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Processing: Part 1

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Processing: Part 2

FISH AS FOOD

EDITED BY

GEORG BORGSTROM

Department of Food Science
Michigan State University
East Lansing, Michigan

VOLUME III

Processing: Part 1

1965

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PREFACE

Utilization of fish and shellfish as human food goes back to early human life on this globe. Drying and salting of aquatic products presumably antedates by a substantial margin the preservation of any other food commodity. Development work in this particular field has been pursued through the centuries and has received the aid of substantial research efforts in a number of countries. It can be seriously argued whether any other category of food has been so extensively studied and investigated and offers so many complex and intriguing technical and scientific challenges.

In preparing what was to be the final volume of "Fish as Food," the overwhelmingly rich amount of information struck even the expert in the field and forcefully indicated, in spite of recent improvements, the lack of a comprehensive abstracting and documentation service in this area in particular as well as in food science in general. Perusal or use of the bibliographic section on fish processing will clearly underline this state of affairs. The extensive lists of references should provide useful and ample documentation to the number of researchers and technologists working in this field as well as in adjacent areas.

In organizing and editing this abundant material it soon became evident that even drastic cutbacks would not allow it being condensed into one single volume, as planned. Reluctantly, but as I hope to the benefit of the scientific community, it was decided to divide this contemplated third volume, covering the general area of the handling and processing of aquatic products into two equally large tomes—the first of which is constituted by this volume.

The international scope of this treatise is retained with contributions from the United States, Europe, the U.S.S.R., and Japan.

One particular difficulty was encountered in the preparation of these volumes. A number of scientific findings are intimately interwoven with technical innovations and industrial developments, and such relationships had to be brought into focus in order to grasp the significance and application of many investigations and discoveries. This was essential especially since the "basic" scientific findings in the fields of fish chemistry, biochemistry, and microbiology were reviewed in Volume I. In order not to detract in any substantial way from a theoretical presentation of these applied areas and in order to place such findings into clear perspective it was decided to include a chapter on the general development of processing at sea (in the next volume) and another on the regional trends in the present development of industrial fisheries (Chapter 12, this volume).

Aquatic products continue to attract attention from food scientists and the general public. These two last volumes fill the recognized gap between production and consumption. Only through wise utilization and efficient processing is it possible to save these extremely perishable riches of the oceans and freshwaters and place them within reach of the consuming public independent of seasons and of fishing fortunes—and mostly far removed from the catching grounds. This is also a prime requisite for fish and shellfish making an essential contribution to alleviating world hunger, looming so seriously over the future horizon of mankind.

I am most indebted to all the contributors to this volume for their effective cooperation and considerable indulgence with all the arduous work involved in rewriting and condensing overrich material. To all I tender my thanks and apologies. It gives me particular pleasure to acknowledge my indebtedness to Dr. Clark Paris, Michigan State University, who throughout these years has given me unstinted help in every aspect of this undertaking, not only in literature searching but also in proofreading and the preparation of the index. Good help has also been rendered by Dr. Sh. Doha, now at East Pakistan Agricultural University, Dept. of Fisheries, Mymensingh. He was employed to aid in various phases of this work, and Mr. Carol Jones, graduate student, MSU, for library research. Finally, I also wish to acknowledge the efficient support I received from the MSU Library in all its branches, and in particular from the Science Division, not only by its head, Dr. Ml. Kabalin, but by all there employed.

GEORG BORGSTROM

East Lansing, Michigan
January, 1965

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CHAPTER 1

Drying and Dehydration

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I. Introduction

A. DEFINITION OF TERMS

Dehydration implies, literally, the removal of water, and the term is often used loosely with this meaning. As such, it can be said to be the basis of most methods of food preservation, as well by salting and freezing as by drying itself or smoking, not to mention fish meal production. However, the term dehydration has come to be restricted technically to any process of drying by controlled, artificial means. Thus, the process by which cod, etc., are hand-dried without salt to produce stockfish, although a form of preservation by drying, is not regarded in this sense as dehydration, as the means of drying is natural, i.e., by exposure to sun and wind. Even dried salt cod, although now mostly produced artificially in controlled dryers, is not, strictly speaking, dehydrated, because it is merely an artificial replica of what was formerly produced by natural means in the open air. Dehydration properly involves not only a measure of control by artifice over the removal of water, but also the preparation of an improved type of product, quite different from the traditional commodities that went before, which were greatly altered in appearance, odor, flavor, and texture by the prolonged curing and drying processes. Probably, since the industrial era provided means of control over air speed and temperature by fans, and heaters, numerous attempts have been made to evolve a drying process resulting in a product which reconstituted perfectly when water was returned to it, so as to be practically indistinguishable from the original, undried fish. It must be said at the outset that, so far as fish is concerned, dehydration as a process has not yet approached the success of freezing in attaining this objective. However, drying, either alone, or in combination with salting or smoking or both together, still accounts for by far the largest quantity of fish used for processing throughout the world.

B. Early Attempts at Dehydration

An early patent was taken out in the United States by Alden (1877) for a process of dehydrating fish. The fish was first trimmed and skinned and cooked in steam on a perforated tray. The bones were then separated, and the flesh was flaked by rubbing through a wire mesh and finally dried on trays in a through-draught dryer. Drying took 3 hr. when the air temperature at the bottom was about 200°F. (93°C.) and that at the top, 100°F. (38°C.). Cooking in water for a few hours, it was claimed, gave the product the appearance, taste, and flavor of fresh fish.

In a further patent (Alden, 1880), filleted fish was cut into pieces dried in an open, steam-jacketed evaporating pan provided with moving blades to prevent sticking and a fan to assist in the removal of water vapor. Drying took 30 to 40 min. and the product, which it was claimed was not cooked but still raw, was said to resemble finely broken vermicelli, and to keep in any climate for a long time. It appears that there was some attempt at commercial development of this process at Gloucester, Mass., about 1880, although it did not succeed in establishing itself (Clark, 1887).

It is said that at Wick in the North of Scotland about 1900 a firm produced, under contract, a drum-dried cod powder coated with cereal for use during the South African War.

World War I led to further investigation in the United States of the possibilities of dehydration (Falk *et al.*, 1919), and it is reported that raw, chopped fish flesh dried in an experimental vacuum shelf-dryer was sent to the Middle East for relief. An account in 1923 of work by the United States Bureau of Fisheries stated (Tressler, 1923a) that drying of fish of low fat content, but not of fatty fish, was carried out commercially in a current of moving air or in vacuum. The more rapid the dehydration, the more rapid was rehydration. The oxidation of even the small amount (0.3%) of fat present in lean fish was considered to result in the formation of an insoluble, hard, impervious film of linoxin on the flakes during slow drying or prolonged storage in air, which caused toughening and impeded the absorption of water. Compact storage in opaque, waterproof containers, in vacuum, or in an atmosphere of inert gas was recommended. Fatty fish, it was stated, could be satisfactorily treated only by drying quickly in vacuum and storing in vacuum or inert gas.

At the same time, details were given (Scott, 1923) of a process which had been given thorough trials on a semi-commercial scale, although not adopted commercially. Fish were first cooked for 20 min. at 12 lb. per sq. in. steam pressure (244°F. [118°C.]) with the loss of 30% of the water. The flesh was then flaked off by hand and minced through a plate with $\frac{3}{16}$-in.-diameter perforations. This was then dried to 5% moisture in 2 hr. in thin layers on trays in air initially at 145°F. (63°C.), and gradually reduced as drying proceeded. The product was coarsely ground and stored either in airtight containers or, for short periods, in paraffin-waxed cartons.

A German process was also described (Tressler, 1923b) in which fish, after cleaning and washing, were pressed to remove some of the water and then hung on racks on trucks in a strong current of ozonized air dried by sulfuric acid and heated by gas. The product was said to have a good appearance and excellent keeping quality.

Roller-drying of fish was patented in 1922 (Townsend, 1922). Macerated, cooked whole fish, or fillets, mixed with hot water, was dried rapidly between rollers heated with steam at 40 lb. per sq. in.

C. United Kingdom World War II Process

The next concerted attempt to dehydrate fish was in Britain in 1939 for war-time use (Cutting *et al.*, 1956), where debulking was an advantage, and this set off parallel investigations in Canada (Young and Sidaway, 1943; Tarr, 1943; Tarr, 1945) and the United States (Young and Lee, 1943; Ham *et al.*, 1944; Stansby, 1945). After investigation of numerous possibilities, the process finally adopted was to mince cooked fish flesh, to dry it in an over-draught dryer under controlled conditions, and to store in cans filled with nitrogen. The best product was arrived at only after exhaustive tests on the effect of minor variations in processing. Although there was no large-scale commercial development of fish dehydration, the output of over 100 tons from a pilot plant in Aberdeen, Scotland, was delivered to the armed forces. The process was sufficiently promising and the product acceptable enough still to merit detailed consideration (see Section IV).

D. Accelerated Freeze-Drying

Postwar developments in vacuum technology have resulted in techniques for drying various products on a large scale at reduced or very low pressures. Among these may be listed pharmaceutical products, coffee and tea essences, and soup mixes. Most of these have the property of being very readily reconstituted.

The process of vacuum freeze-drying (see Section III) as applied to fish is the only dehydration method yielding a product which, on reconstitution, resembles the original raw material. Until recently, fish had been dried by this method on only a small scale, and the time necessary to remove most of the water was too great to suggest commercial feasibility. However, a much more rapid method of freeze-drying has recently been developed at the Experimental Factory of the British Ministry of Agriculture, Fisheries and Food, for various foodstuffs including fish, although fish itself has so far not been prepared commercially in this form. A more detailed account of this process is deferred until Section III, G.

II. Theoretical Aspects of Fish Drying

A. Generalized Elementary Treatment of Basic Mechanisms of Drying

In any process of drying or dehydration, consideration must be given to the conditions of mass- and heat-transfer and to certain thermodynamic properties of the system. The outward movement of water in the sequence

> migration within material ⟶ removal from surface ⟶ mixing with atmosphere surrounding material ⟶ removal from vicinity of surface

must, in conventional methods of drying, be accompanied by the inward transfer of heat indicated by the sequence

> emission from source ⟶ transfer to surface ⟶ conduction within material ⟶ provision of latent heat of evaporation and partial enthalpy of dilution of system regarded as a solution.

Thermal energy to drive off the water can, however, be provided directly by such means as irradiation with a beam of microwave electromagnetic radiation, radio-frequency dielectric heating, or ultrasonic heating.

The relative importance of the various mechanisms involved depends upon the nature of the material being dried, the internal and external conditions, the means of supplying thermal energy, and the water content. In some methods of drying, one or more of these mechanisms may not be limiting factors and consideration of them can be disregarded.

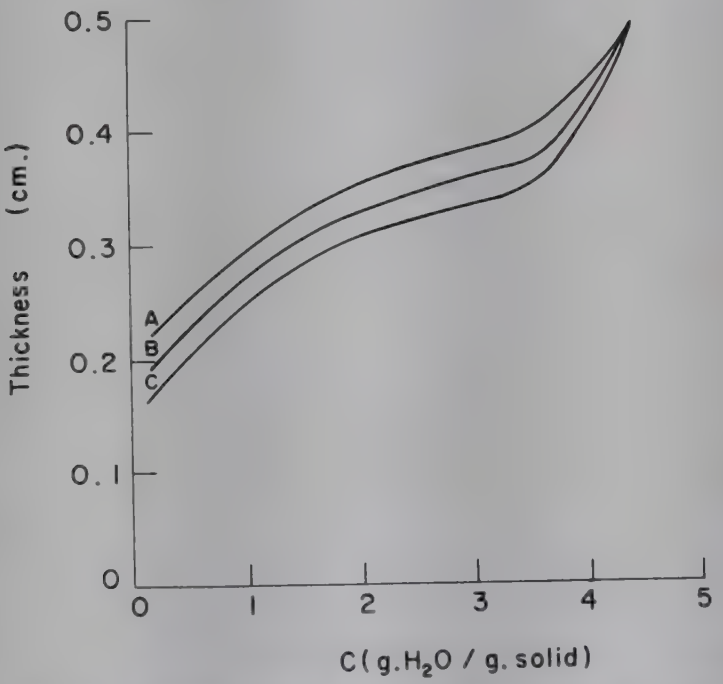


FIG. 1. Relationship between mean water concentration and thickness measured at centers of cod fillet pieces initially 4 × 4 × 0.5 cm.^{3}. Curve A: transverse section; curve B: horizontal longitudinal section; curve C: vertical longitudinal section.

Fish muscle in its native state may be regarded as a gel. When dried at a temperature above its freezing point, it remains a gel until it has lost a considerable amount of water. During this process, severe shrinkage takes place (Fig. 1). When frozen, it dries progressively from the outside without shrinkage, and forms a porous layer which surrounds the inner undried region. A sharp plane of demarcation exists between the dried and undried material. Unfrozen, fish muscle, with few exceptions, is practically an isotropic medium at any water content; frozen, it behaves anisotropically as it dries. This difference in behavior arises from the physical properties of the muscle structure under these two very different conditions of drying. The role of some of these properties in each of the various mechanisms of drying will be discussed further under separate headings.

All traditional methods of fish drying are carried out at ambient or elevated temperatures. Only in recent times have various processes been developed for drying food in the frozen state, but none of these is yet in commercial operation. Much experimental and theoretical work has been done to elucidate the mechanism of the drying of materials in air, and a somewhat smaller effort has been directed toward understanding the process of drying materials in the frozen state under reduced atmospheric pressure (freeze-drying), but very little attention has been directed toward a systematic understanding of the lesser-known methods described below, such as vacuum fat drying or infrared drying. Among the materials studied, fish, as indeed have most foodstuffs, has been sorely neglected.

The remainder of this general discussion on the various basic mechanisms involved in drying fish will be devoted principally to the treatment of air drying but, where relevant, attention will be drawn to the significance of particular basic aspects in the understanding of other methods of drying.

According to simple kinetic theory (Dorsey, 1940), the total mass of a substance escaping from unit area in unit time from a liquid (or solid) of molecular weight M at absolute temperature T is[1]

$$m_e = \alpha M p_{\text{sat}} / (2\pi MRT)^{1/2} \tag{1}$$

where α is the coefficient of capture of vapor molecules by the denser phase, p_{sat} is the saturation vapor pressure of the substance at temperature T, and R is the gas constant.

At 10°C. α is 0.036 for water (Alty and Mackay, 1935), which gives a calculated value of 4.9 mg./sec. cm.^{2} for m_e. Observed values for the rate of evaporation of water in an air stream depend considerably on the conditions, as will be shown later, but are of the order 10 mg./hr. cm.^{2} or about one ten-thousandth part of the theoretical value based on simple kinetic considerations. The principal reason for this very great discrepancy arises from the presence of a stagnant layer of air which blankets the surface. In order to escape, water molecules must diffuse through this layer into the turbulent zone beyond. The net rate at which they do so depends upon the product of the diffusion constant and the vapor pressure on the side remote from the water (or ice).

If the surface is being dried in a stream of air, the stagnant layer becomes a layer of laminar flow, sometimes called the "boundary layer," whose thickness depends upon the aerodynamic conditions at the surface. Both the thickness of the layer and the coefficient of diffusion of water vapor in air are the limiting factors, the latter depending on temperature and the partial pressure of the air. Although the coefficient of diffusion does not depend strongly on temperature, it is very sensitive to air pressure and, as would be expected, the rate of evaporation of water is greatly enhanced if drying takes place in an evacuated space.

---

[1] For a complete list of symbols used in this chapter, see p. 51.

It has been shown (Jason, 1959) that during the initial stages of drying the surface of fish muscle behaves as though it were a saturated surface and that the laws which apply to the drying of such surfaces may be applied to fish in practical calculations. During this period, the rate of evaporation is uniform and is the maximum that aerodynamic and heat flow conditions will permit. This stage of drying is known as the *constant-rate period.* However, Leniger (1959) has pointed out that, as far as most foodstuffs are concerned, such a conclusion, though substantiated experimentally for a number of substances, is not strictly admissible on theoretical grounds. The reason is briefly as follows. Immediately drying commences, the water content at the surface tends to fall rapidly because the rate of diffusion within the solid is not sufficient to maintain the initial value. The water content therefore approaches the equilibrium value indicated by the vapor pressure isotherm (shown for cod muscle in Fig. 2). Figure 3 (due to Leniger) shows diagramatically the form of the vapor pressure profile through the sample and the layer of laminar flow after various times of drying. Quite clearly, if it is assumed that the rate of diffusion of water through the layer of laminar flow is dependent upon the vapor pressure difference across it, then the rate of drying can never be constant.

In the case of fish muscle, which initially has a water content of about 4 g. H_2O/g. dry weight, the vapor pressure remains substantially at its saturation value until the water content falls below about 1 g. H_2O/g. dry weight. It is for this reason that the constant-rate period is a practical reality, though it is important to recognize the correctness of Leniger's analysis.

In practice, the constant-rate period is terminated when the rate of diffusion of water from the interior of the muscle cannot maintain a sufficient flow to the surface to sustain the initial maximum rate of evaporation. The termination of the constant-rate period is followed by a rapid decline in the drying rate. The rate of drying continues to decrease and becomes negligibly small as the water content of the fish muscle approaches an equilibrium value. During this, the *falling-rate period,* internal diffusion is the principal controlling factor. The flux f

at a point at which the concentration of water is C is given by Fick's Law

$$f = -D \text{ grad } C$$

where grad C is the concentration gradient at that point and D is the diffusion coefficient. It is then a simple matter to show that the rate of change of concentration is given by the Fourier equation

$$\frac{\partial t}{\partial C} = \mathrm{D}\ \nabla^2\ C \qquad (2)$$

For a given set of boundary conditions it is then possible to derive the water concentration at any point at a given time t after the commencement of drying and the total unaccomplished weight loss at that time.

During the process of drying, a substance loses heat mostly by

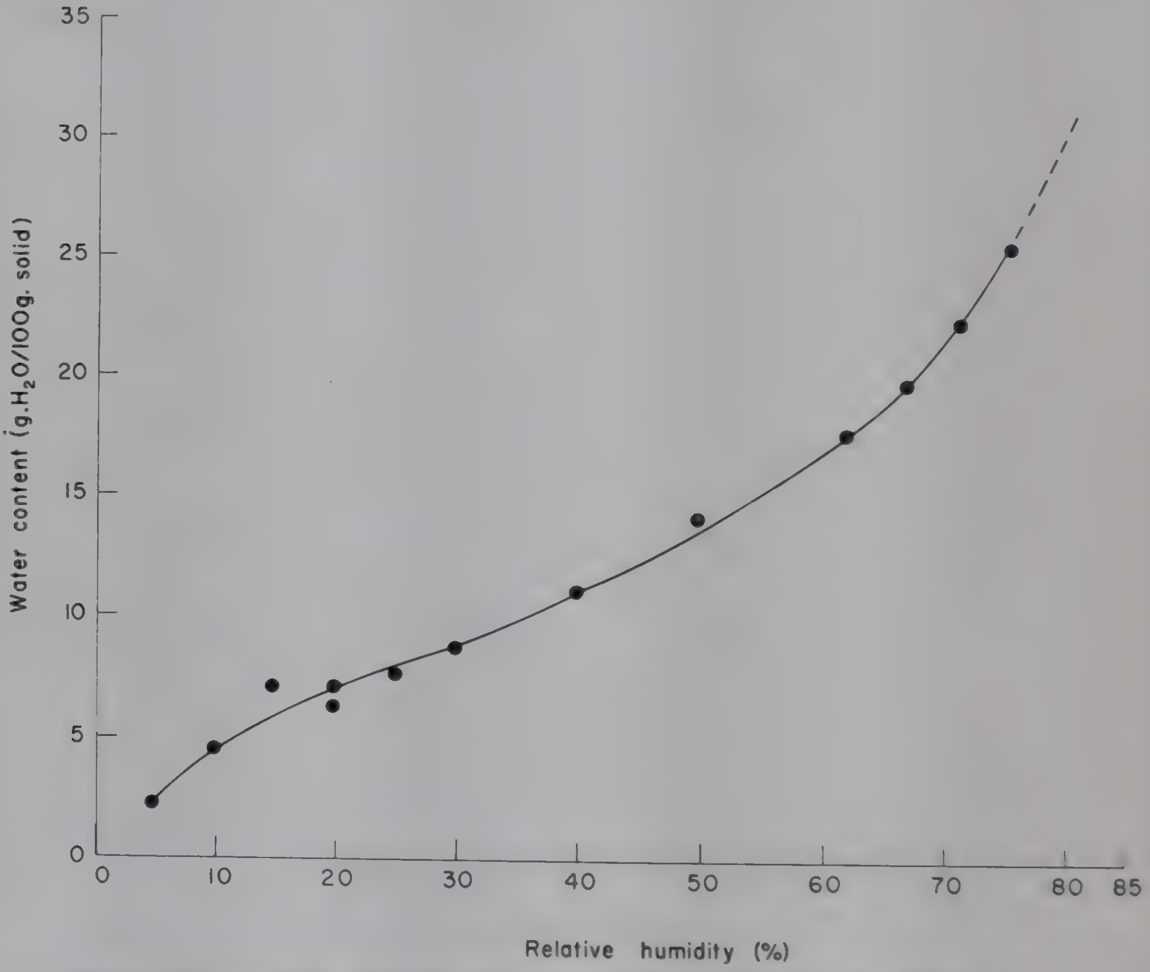


FIG. 2. Relationship between equilibrium water content of cod muscle and relative humidity at 30°C.

evaporation of water from the surface. The rate of loss of heat H due to such evaporation is

$$\frac{-dH}{dt} = L\frac{dW}{dt} \tag{3}$$

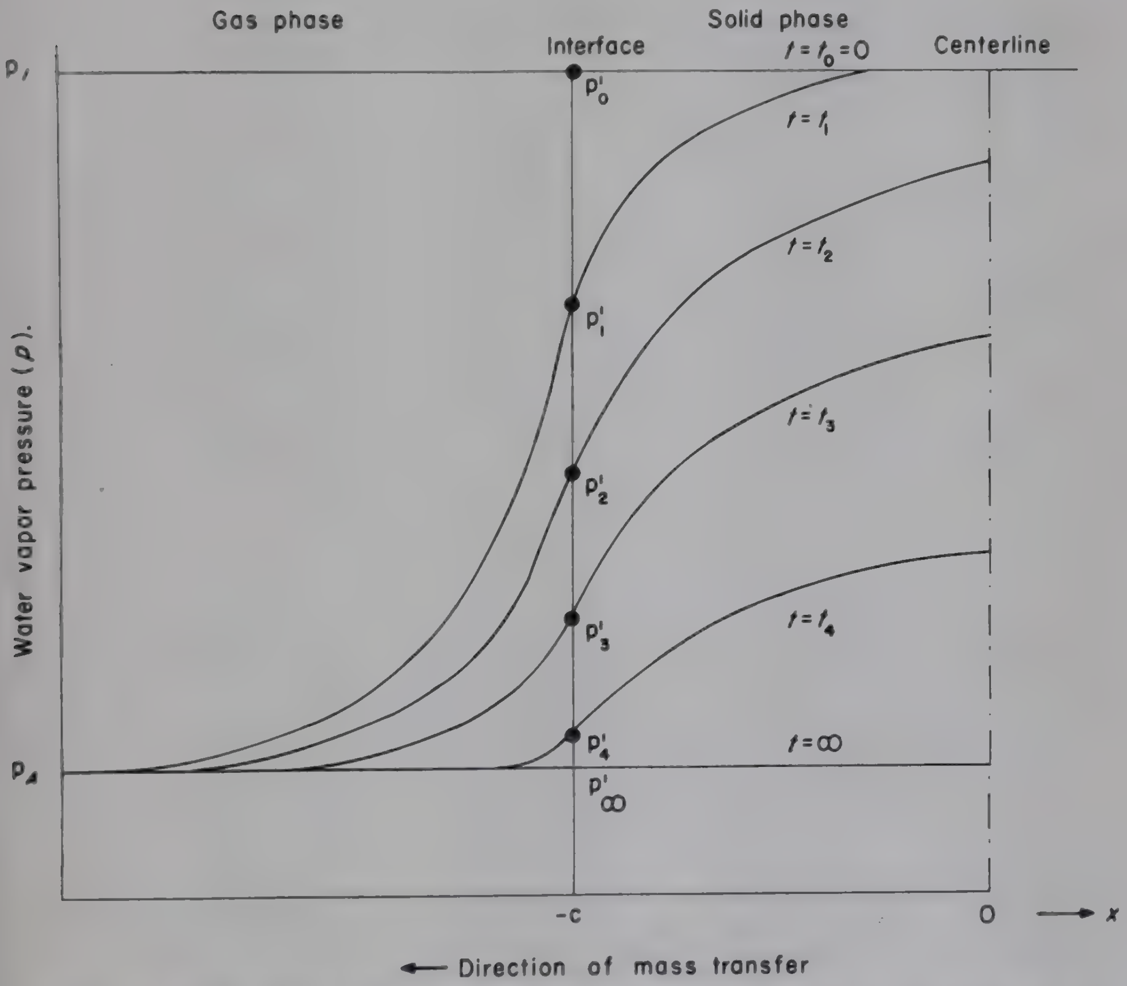


FIG. 3. Water vapor pressure profile through solid material of thickness $2c$ and surrounding layer of air at various times t after commencement of drying (after Leniger, 1959). p_I = initial vapor pressure; p_A = partial pressure of water vapor in surrounding atmosphere; p_0, p_1, p_2, ... = pressure at interface at times t_0, t_1, t_2, ... respectively.

where W is the weight of water. L, the latent heat of vaporization of water at surface temperature T_s degrees absolute ($= 273.1°\text{C.} + \theta_s$), is given by Clapeyron's equation

$$\frac{dp_s}{dT_s} = \frac{L}{T_s}(v_2 - v_1)$$

where p_s is the partial pressure of water vapor at temperature T_s, and

v_2 and v_1 are the specific volumes of water in the liquid and vapor phases, respectively. The above equations are applicable to fish muscle at all values of water content down to about 25% (on a dry basis), below which account must be taken of the heat of wetting. Thus, to the latent heat of vaporization must be added a term for the partial enthalpy of dilution Δh of the system. This may be derived from the effect of temperature on the vapor pressure of water in equilibrium with a sample of muscle of given water content

$$\Delta h = - \frac{RT_s^2}{M} \frac{\partial}{\partial T} \left[\ln \frac{p}{p_{\text{sat}}} \right]_W \tag{4}$$

where M is the molecular weight of water, the saturated vapor pressure is p_{sat} and the vapor pressure of water in equilibrium with the muscle at a given water content W is p. The contribution of this term becomes increasingly significant as the system becomes drier.

In order to sustain drying at a rate dW/dt, heat must be transferred to the surface at a rate

$$\frac{dH}{dt} = k_h A \, (T_a - T_s) \tag{5}$$

where H includes the contributions from (3) and (4), k_h is the effective heat transfer coefficient, A is the surface area and T_a is the air temperature.

The coefficient of mass transfer k_w may be defined by the relationship

$$-\frac{dW}{dt} = k_w A \, (p_s - p_a) \tag{6}$$

where p_a is the partial pressure of water vapor in the air.

Combining (3), (4), (5) and (6) gives

$$\frac{p_s - p_a}{T_a - T_s} = \frac{1}{L + \Delta h} \frac{k_h}{k_w} \tag{7a}$$

But, except in the near dry state,

$$\frac{p_s - p_a}{T_a - T_s} = \frac{1}{L} \frac{k_h}{k_w} \tag{7b}$$

is a sufficiently good approximation.

The above considerations also apply for all values of the partial pressure of air, but, as the partial pressure is progressively reduced, consideration of convective mass- and heat-transfer becomes less and less important. Ultimately, to sustain evaporation, heat has to be provided by conduction or radiation. Under conditions in which the mean free path of the air molecules is comparable with the dimensions of the dryer, the maximum possible rate of drying is given by Equation (1). However, in practice this rate can never be achieved, owing to severe limitations imposed by certain physical properties of the material being dried. Nevertheless, the rate of drying is normally so very rapid under these conditions that evaporative cooling is sufficiently great to freeze the material and to maintain it in the frozen state. When this occurs, the mechanism of migration of water molecules within the material is very different from that taking place when the material is not frozen. The drying behavior of fish muscle under conditions of reduced air pressure will be considered from the theoretical standpoint in Section II, E.

B. Physical Properties of Fish in Relation to Drying

There is a great paucity of data relating to the physical properties of fish muscle. Here and there in the literature are to be found references to one or another property measured in connection with a particular investigation. More often than not the value relates to a single measurement, and no indication is given of the effects of biological variation. Only rarely does an author offer results for more than a few species.

In the light of these remarks, it is not surprising that few data relating to the drying of fish can be found. The tables that follow will, however, give sufficient information on which to base reasonably accurate calculations for most nonfatty white fish, since in several respect there appears to be, roughly speaking, a certain invariance in physical properties amongst the species.

In general, each set of data or piece of information given derives from a single source, but in some cases where more than one source has come to the notice of the compiler, references are given in each case considered to be of importance. The definitions of the physical properties tabulated are those commonly accepted, and it is thought unlikely that there will be any ambiguities. The normal system of units adopted is that based upon the centimeter, gram, and second (the c.g.s. system).

1. *Density*

a. The Native State

Observations by the author on most species of common sea fish suggest that the density of their skeletal muscle is close to that of cod (*Gadus callarias*), but no accurate figures are available. For most practical purposes it may be assumed that, following Long (1955), the variation of density with temperature of the majority of these can be obtained by a combination of the specific volumes of the various constituents. The figures (in Table Ia) based on this assumption give the density ρ at various temperatures θ of fish muscle containing approximately 80% of water.

Table Ia

Density of Cod Muscle at Various Temperatures[a]

θ	—20	—15	—13	—10	—7	—5	—4	—3	—2	—1	0	5
ρ	0.980	0.981	0.981	0.982	0.983	0.988	0.991	0.998	1.016	1.046	1.043	1.027

[a] Unit of ρ = 1 g./cm.^{3}; temperature = θ°C.

Lobsin (1939) gives a few results (Table Ib) for muscle of pike perch (*Lucioperca lucioperca*) and presents a semi-empirical theory for the variation of density with temperature. The measurements made at temperatures above 0°C. show an unexpected increase with increasing temperature.

Table Ib

Density of Pike Perch Muscle at Various Temperatures[a]

θ:	—11	0	5	15
ρ:	0.988	1.050	1.051	1.064

[a] Unit of ρ = 1 g./cm.^{3}; temperature = θ°C.

b. The Dried State

Cutting *et al.* (1956, pp. 66–68) give figures (Table Ic) for the density of dehydrated (air-dried) herring (*Clupea harengus*) of different fat and water content (F and W) and of dehydrated (air-dried) cod at 20°C., determined by means of a volumenometer in order to obviate errors resulting from porosity.

Voskresensky (1959), using benzene in a pycnometer to find the

Table Ic

Density of Dehydrated Herring and Cod of Different Fat and Water Content[a]

Sample	F	W	ρ
Dehydrated herring	1.19	0.09	1.13
	1.19	0.10	1.13
	0.75	0.05	1.15
	0.75	0.08	1.16
	0.75	0.10	1.16
	0.75	0.13	1.17
	0.53	0.12	1.18
	0.53	0.10	1.19
	0.53	0.14	1.19
Dehydrated cod	0.01	0.04	1.31

[a] Unit of F = 1 g. fat per gram fat-free solid; of W = 1 g. water per gram fat-free solid; of ρ = 1 g./cm.^{3}.

true density of vacuum freeze-dried cod muscle at 20°C., gives $\rho = 1.30$. The total pore volume for the same sample was 1.06 $cm.^3/g$.

2. *Water Content*

With the exception of some recent work on the seasonal variation of the water content of cod muscle (Love, 1960), systematic information on the water content of all fish muscle except those of herring and red fish is lacking. It can be safely assumed, however, that the muscles of nonfatty fishes in general contain between 79 and 85% water, although values well outside this range have been found, and freak values of as high as 96% have been reported for certain diseased specimens (Templeman and Andrews, 1956).

a. COD

Love (1960) measured the water content (Table IIa) of muscle tissue free from myocommata (connective tissue) in three size groups of cod: (1) 51 cm. long or less; (2) close to 76 cm.; (3) 92–107 cm. In each group values were found to vary throughout the year (W = water content).

TABLE IIa

WATER CONTENT OF MUSCLE TISSUE IN THREE SIZE GROUPS OF COD[a]

Month	*W* in size groups: 1	2	3
January	80.7	80.4	80.6
March	81.5	81.9	83.3
April	80.6	81.7	82.7
June	80.5	80.4	—
July	80.0	80.2	80.2
October	80.7	80.4	79.6
November	80.5	80.8	80.2

[a] Unit of $W = 1\%$ of total weight.

b. HERRING

Brandes and Dietrich (1953) have found that there is a close relationship between fat content F and water content W in herring which is independent of season, degree of maturity, and fishing ground. This indicates that the water content decreases linearly with fat content. In the whole fish the relationship is represented by the expression

$$F = 0.980\,(80.6 - W)$$

in which all values are expressed as percentages. The corresponding expression for the edible portion only is

$$F = 1.1505\,(80.4 - W)$$

The values (in Table IIb) of water content have been calculated from these expressions for a few values of fat content.

TABLE IIb

WATER CONTENT CALCULATED FROM FAT CONTENT[a]

F	W (whole fish)	W (edible portion)
5	75.6	76.1
10	70.4	71.8
15	65.3	67.6
20	60.2	63.3
25	55.1	59.1

[a] Unit of F and of W = 1% of total weight.

c. REDFISH

As in the case of herring, Brandes and Dietrich (1956) have shown that there is a high correlation between fat content and water content of the edible portion of redfish (*Sebastes marinus*). The correlation is independent of the biological state of the fish and is represented by the expression

$$F = 1.1655\,(81.07 - W)$$

which is almost identical with that for the edible portion of herring as is shown by the few values in Table IIc.

TABLE IIc

CORRELATION BETWEEN FAT AND WATER CONTENT IN EDIBLE PORTIONS OF REDFISH[a]

F	W
5	76.8
10	72.5
15	68.2
20	63.8
25	59.5

[a] Unit of F and W = 1% of total weight.

3. *Equilibrium Water Content*

As with most other biological materials, there is an equilibrium relationship between water content w relative to dry weight and the relative pressure p/p_{sat} (where p is the pressure and p_{sat} is the saturation vapor pressure) of the water vapor. A typical isotherm for cod muscle is shown in Fig. 2. This has the appearance of a Type-II adsorption isotherm for which Brunauer (1955) has put forward a multimolecular adsorption theory for adsorption taking place on a free surface. The theory is consistent with the adsorption behavior of cod muscle up to a relative vapor pressure of about 0.6. Although the water content at a given relative vapor pressure is related to temperature and the partial enthalpy of dilution [see Equation (4)], the effect of temperature on the shape of the isotherm is not very great. In practice there is generally a small drop in water content with an increase in temperature at a given relative pressure.

The values in Table III have been selected by the compiler from a number of isotherms given by Cutting *et al.* (1956, pp. 66–68) for raw and processed fish of various species, as being most relevant to the purposes of this review.

TABLE III

EQUILIBRIUM WATER CONTENT[a]

	w in product:							
	Vacuum freeze-dried raw cod	Air-dried cooked cod		Rolled-dried cooked whiting		Air-dried cooked herring		
p/p_{sat}	10°C.	15°C.	37°C.	10°C.	37°C.	0°C.	15°C.	25°C.
0.05	5.3	—	—	—	—	—	—	—
0.10	6.1	5.2	4.2	5.3	4.3	5.1	4.6	4.5
0.20	7.9	—	—	—	—	—	—	—
0.30	9.6	7.2	6.5	7.3	6.6	7.2	7.3	7.4
0.40	11.5	—	—	—	—	—	—	—
0.50	14.1	10.8	10.2	9.9	9.1	10.5	10.8	10.8
0.60	17.0	—	—	—	—	—	—	—
0.65	—	14.9	13.9	—	—	—	—	—
0.70	21.6	—	—	18.9	17.3	18.1	17.3	16.5
0.75	—	19.9	18.8	—	—	—	—	—

[a] Unit of w = 1 g. water per 100 g. dry weight, or, for herring 1 g. water per 100 g. fat-free dry weight.

4. *Thermal Conductivity of Raw Fish Muscle*

Fish muscle may be regarded as a mixture of water, fats, sugars, salts, and solids (both soluble and insoluble). Below freezing point, the mixture is one of sugars and salts in solution in concentrations depending on temperature, plus ice crystals, fats, and solids.

Long (1954, 1955) has carried out an approximate theoretical analysis based on a formula by Maxwell which enables the apparent thermal conductivity to be derived from the known thermal conductivities of the principal constituents. Theoretical values were found to be in excellent agreement with measured values for cod muscle over the entire range of temperature investigated —29° to +2°C. (—20.2° to +35.6°F.).

Apart from Long's results, the only other values that the compiler can find in the literature relating to individual species are those of Lobsin (1939) for the muscle of pike perch. However, the data are of limited value, owing to the large temperature differences maintained across the samples. Although this is not quite so important in measurements of the thermal conductivity of unfrozen muscle, the results have little or no meaning when the thermal conductivity varies markedly with temperature in the region between the "hot" and "cold" surfaces.

The values in Table IVa for the apparent thermal conductivity k_a of the muscle of cod at various temperatures θ are those given by Long (1954, 1955).

TABLE IVa
THERMAL CONDUCTIVITY OF THE MUSCLE OF COD[a]

θ	0	—1[b]	—2	—3	—4	—7	—13	—21.9[c]	—21.9[d]	—29
k_a	13.2	13.1	26.7	31.9	34.3	37.8	41.3	41.5	43.4	43.9

[a] Unit of $k_a = 10^{-4}$ cal./cm. sec.°C.; temperature = θ°C.
[b] Freezing point.
[c] Just above eutectic point.
[d] Just below eutectic point.

Lobsin (1939) obtained an average value for k_a between 0° and 40°C. for pike perch of 11.2×10^{-4} cal./cm. sec.°C. At subzero temperatures the values in Table IVb were obtained over the temperature range indicated.

TABLE IVb
THERMAL CONDUCTIVITY OF PIKE PERCH MUSCLE

θ:	—3.5 to —6.8	—6.8 to —11.1	—11.1 to —15.8	—15.8 to —21.2
k_a:	21.7	25.7	30.1	33.0

Katchaturov (1956) plotted values of thermal conductivity for various species of fish as a function of temperature and drew a mean curve through the points from which the values in Table IVc were derived:

TABLE IVc
AVERAGE THERMAL CONDUCTIVITY OF VARIOUS SPECIES OF FISH

θ:	0	—5	—10	—15	—20	—30
k_a:	11.1	25.5	29.1	31.1	32.8	34.7

The fact that these values are consistently lower than those given by Long may be attributed to the weighting of the contributions from the fatty fish, which have lower values of k_a than have nonfatty fish.

5. *Thermal Conductivity of Vacuum Freeze-Dried Cod Muscle*

The compiler can find no values in the literature for the thermal conductivity of vacuum freeze-dried fish and has therefore made a few determinations by the heated probe method (Mann and Forsyth, 1950) in order to tabulate values to be used in a later section.

The values in Table V show that there is little difference between the thermal conductivity k of vacuum freeze-dried cod measured across steaks (i.e., in a direction parallel to the sagittal plane) and that measured across fillets. Measurements were made in air at atmospheric pressure and at a pressure of 3 mm. Hg.

TABLE V

THERMAL CONDUCTIVITY DIFFERENCES BETWEEN STEAKS AND FILLETS OF COD[a]

	k at 760 mm. Hg	k at 3 mm. Hg
Steak	1.51	1.04
Fillet	1.54	1.13

[a] Unit of $k = 10^{-4}$ cal./cm. sec. °C.

6. *Diffusion Coefficient of Water in Fish Muscle*

The diffusion coefficient D is defined by the formula $\delta m/\delta t = -D\, dC/dx$ where δm is the mass of water crossing unit area in time δt in the direction of increasing x when the gradient of concentration (mass per unit volume) is dC/dx.

In fish muscle the diffusion properties of water are practically isotropic and nearly all species of nonfatty fish possess the same diffusion coefficient (Jason, 1959). If the coordinate system is related to the configuration of the muscle in the native state and is allowed to shrink

TABLE VI

DIFFUSION COEFFICIENT OF WATER IN FISH MUSCLE[a]

θ	D_1	D_{11}
10	1.55	0.127
20	2.40	0.212
30	3.43	0.345
40	5.24	0.556
50	7.39	0.818
60	10.1	1.27
70	13.9	1.80
80	18.8	2.65
90	25.0	3.75
100	32.0	5.16

[a] Unit of D_1 and $D_{11} = 10^{-6}$ cm.^{2}/sec. Temperature $= \theta$°C.

with the nonaqueous material as drying proceeds, then the effective diffusion coefficient remains constant until the mean water concentration falls to approximately 0.1 g. H_2O/g. solid; below this concentration the diffusion coefficient diminishes quickly and again assumes a constant value until the water concentration falls below about 0.01 g. H_2O/g. solid. The initial value is denoted by the symbol D_i and the second value by D_{ii}. Table VI shows values in the range of temperature θ from 10° to 100°C.

C. Categories of Possible Methods of Drying

A priori considerations show that there is a variety of possible methods of drying solid materials. Each method may be categorized by the way in which thermal energy is supplied to the water molecules to drive them from the substrate and by the mechanism of removing water vapor from the immediate environment of the material. Although a wide variety of methods is listed below, not all are suitable for commercial application in fish drying. Those which are feasible are described in Section III.

1. *Air Drying*

At the surface of the material, air performs the dual function of providing heat by convection and of removing water. This can take place with the material in either of two states, unfrozen or frozen.

The former condition obtains, of course, during normal air drying. The latter condition is the familiar "freezer burn" that occurs in unwrapped or unglazed food during cold storage and is normally an undesirable feature of low temperature storage.

Unfrozen fish shrinks during drying. When dried to a low water content, it is hard and dense and it takes many hours to reconstitute. In this form it is known as *stockfish.* When it is salted and dried as *salt-fish,* the water content is usually somewhat higher, and the product has a rubbery consistency.

Frozen fish retains its shape when dried in air, and although it will partially reconstitute fairly rapidly, the deterioration due to oxidative changes which take place during the process of drying makes the reconstituted product unacceptable as a food. The process is known as freeze-drying.

Freeze-drying in air has recently been reported by Meryman (1959) as a method of drying small samples of biological tissue, but no evaluation has yet been given of the practicability of this method for drying food, nor of the quality of the product.

2. *Roller Drying*

Rapid heat transfer by means of a heated roller in contact with the material under pressure offers a method by which food can be dried continuously in air.

3. *Vacuum Drying*

A solid material containing water dries rapidly at first when placed in an evacuated chamber and quickly cools as it supplies latent heat to evaporate the water. If sufficient heat can be supplied to prevent freezing due to evaporative cooling, or if the water vapor pressure within the chamber is allowed to rise above that of ice, the material will dry much as it does in air. However, if insufficient heat is provided, the material will freeze. In the absence of external heat, fish freezes after approximately 15% of the water has evaporated.

There are therefore two possible modes of drying in an evacuated enclosure, vacuum drying and vacuum freeze-drying.

Vacuum-dried fish shrinks as does air-dried fish, and the rates of drying in the two processes are comparable. Vacuum freeze-drying, on the other hand, can be more rapid because resistance to the flow of water vapor through the dry porous outer layer (which forms as the ice boundary recedes) is less than resistance to the flow of molecules in diffusing through the partially dried gel which constitutes the medium in the unfrozen state.

In practice, the rate of vacuum freeze-drying is limited mainly by the rate of heat transfer through the dry material to the ice boundary, at which the latent heat is required. The term "vacuum freeze-drying" has until recently been applied to the process in which latent heat is provided only by radiation from the walls of the chamber. Such a method cannot, of course, enable rapid drying to take place. For this to be possible, heat must be supplied either at a high rate to the outer surface of the fish, or by one of the methods categorised in subsections 4–7 below.

Among the methods of direct heat transfer which have practical significance are the following:

(i) vacuum contact drying;
(ii) accelerated freeze-drying;
(iii) heated spike freeze-drying;
(iv) vacuum fat-drying.

Practical aspects of these methods will be described in Section III.

In each of the methods referred to, water vapor must be removed rapidly from the chamber. This is accomplished either by means of a desiccant, by condensation on refrigerated surfaces, or by means of steam ejector pumps.

4. *Ultrasonic Drying*

Heat for evaporation of ice in the vacuum freeze-drying process could, in principle, be induced by subjecting frozen fish to ultrasonic vibrations of high intensity. However, the difficulties of efficiently coupling an ultrasonic transducer to the outer surface and of ensuring that heat is produced at the ice surface or in the frozen material, together with the high cost of ultrasonic power, suggest that such a method is not practicable on a large scale.

5. *Radio-Frequency Drying*

The provision of latent heat by radio-frequency dielectric heating has been used by Besser and Piret (1955) in an investigation of the drying of gelatin and paper pulp in air, but these authors have concluded that the method confers no advantage in the drying process for these typical colloidal and typical fibrous materials. This is probably because convective heat transfer and thermal conduction in normal air drying are sufficiently high to maintain any desired temperature within these materials. In vacuum drying or vacuum freeze-drying, radio-frequency heating would appear to be an ideal solution to the problem of supplying latent heat, since power is absorbed preferentially by wet material and the transmission of power is unaffected by the outer insulating layer of dried material. Unfortunately, at pressures normally encountered in vacuum drying, corona discharge occurs between the electrodes and the material. This gives rise to severe scorching which takes place both at the surface and within the material. Such discharge can be prevented by increasing the frequency of the applied field in order that adequate power can be dissipated with a sufficiently low electrode potential to prevent corona discharge. The frequency above which this condition is reached is considerably in excess of 100 Mc/s. It can be shown that, at such frequencies, standing waves of the order of 10 cm. in length are generated in the material which would give rise to extremely uneven heating on a practical scale. Thus these two factors—corona discharge at the lower radio frequencies and standing waves at the higher frequencies—combine to prevent the application of this form of heating.

6. *Microwave Drying*

Copson and Decareau (1957) have shown that, provided certain precautions are taken to avoid a slight risk of corona discharge, a beam of radiation at a frequency of 2450 Mc/s can be used in freeze-drying to warm samples of beefsteak weighing a few tens of grams. However, the difficulties of applying this method on a large scale are prohibitive, first because high-power microwave radiation cannot be produced at present without employing a multiplicity of magnetrons, and secondly because both attenuation of the microwave beam within the material and uneven heating are practically unavoidable in bulk foodstuffs.

7. *Infrared Drying*

Finally, consideration must be given to the most easily produced radiation in the electromagnetic spectrum—infrared radiation. Its wavelength is shorter than those of the other sources considered, lying in the range 7×10^{-5} cm. to about 1×10^{-2} cm.

Its chief virtue is that it provides a convenient and efficient method of transferring heat to irregular surfaces and for this reason it has been used frequently to dry both porous and nonporous materials. Although it can be used to dry solid foodstuffs in air, infrared heating offers no great advantage over convective heat transfer because the surface cannot be heated beyond the temperature at which damage occurs and because transfer of water vapor must take place by convection in an air stream in any case.

The application of infrared radiation in freeze drying would provide a solution to the problem of conveying heat to and through the outer dried layer if, over a certain range of wavelength, the dried layer was transparent to the radiation but the remaining frozen material was opaque or absorbent. A search has been made by Preston (1958) for a "window" in freeze-dried cod muscle in the range of wavelength from 7×10^{-5} cm. to 2.5×10^{-3} cm., but without success. Owing to consistently high absorption, infrared radiation of any wavelength in this range can do no more than heat the surface. Its usefulness is limited, therefore, to providing heat at the surface of an irregular-shaped material or where contact between a heated plate and the material is not possible.

D. PHYSICS OF AIR DRYING

The following treatment is an elaboration of the considerations given in Section II, A above and is concerned in showing that the drying behavior of fish is not arbitrary, as has often been supposed, but conforms largely to well-known laws of physics.

Evaporative cooling of the surface of a fish is an important factor in certain drying processes, as it enables high air temperatures to be maintained, while at the same time preventing the surface from becoming overheated, as, for instance, in the cold smoking process. Equation (7a) shows that the magnitude of the cooling effect is linearly related to the pressure difference across the boundary layer because L, k_h, and k_w are practically constant. Thus Equation (6) suggests that $-dW/dt \propto (\theta_a - \theta_s)$ throughout both periods of drying, except at the lowest water contents. Figure 4 is an example showing this to be true.

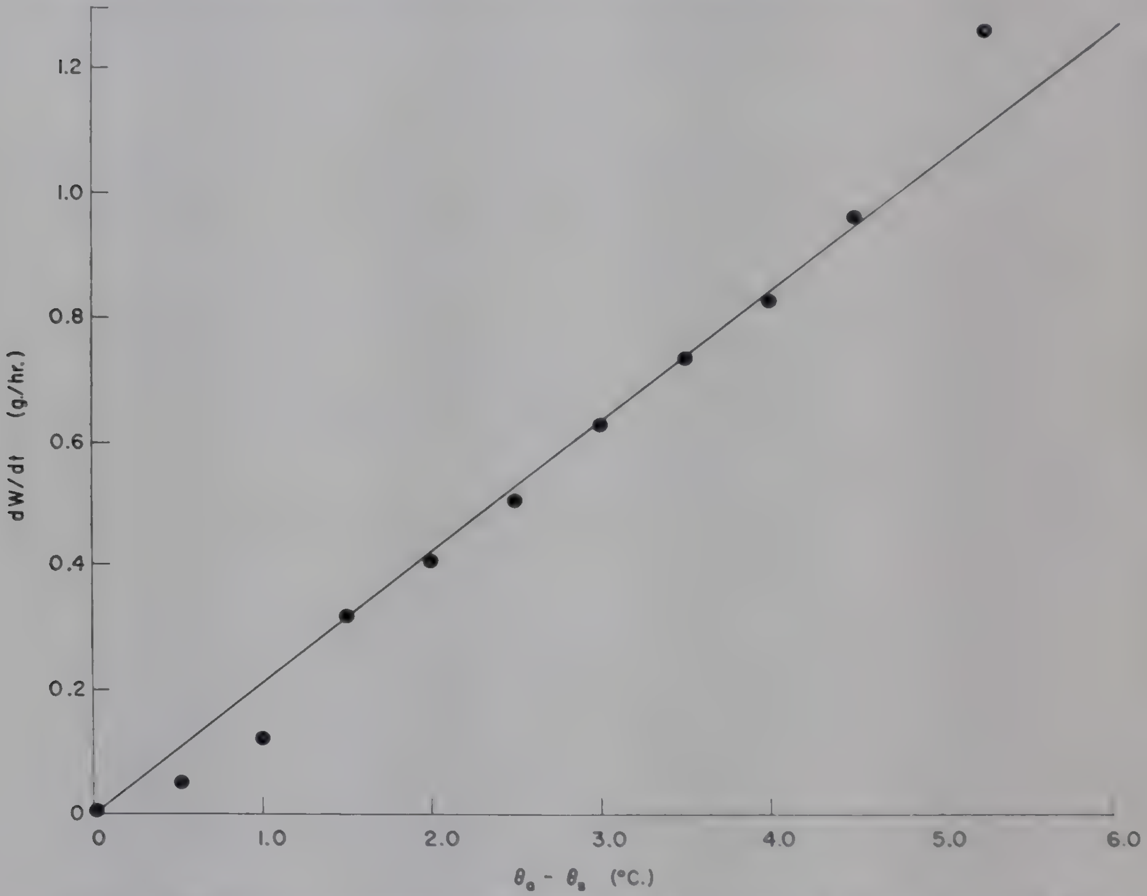


FIG. 4. Relationship between surface cooling and rate of drying for cod fillets exposed to an air stream of velocity 30 cm./sec. Dry-bulb temperature 30°C.; wet-bulb temperature 18°C.

In the absence of radiation or conduction, θ_s is equal to the wet-bulb temperature θ_w during the constant-rate period, since the same considerations apply equally to the surface of a fish and a wet-bulb. Equation (6) together with the equation of Apjohn (1835)

$$p_w - p_a = BP(\theta_a - \theta_w)$$

(which relates the difference $p_w - p_a$ between the saturation vapor pressure at the temperature of the wet-bulb and that in the air, and the wet-bulb depression, where B is a constant and P is atmospheric pressure), indicate that at a given air velocity the rate of evaporation per unit area

$$-(dW/dt)/A = \varepsilon = \text{constant} \times (\theta_a - \theta_w) \tag{9}$$

This shows that the rate of drying is proportional to the wet-bulb depression and is independent of the air temperature. This is seen in Fig. 5 to hold fairly well over a range of air temperature from 20° to 100°C.

Drying rate is shown in Fig. 6 to be related to air velocity u by a power law of the form

$$\varepsilon = \text{const.} \times (\theta_a - \theta_w)u^n \tag{10}$$

This is of the same form as the heat transfer equation recommended (Marshall and Friedman, 1950) for the constant-rate in drying from plane water-saturated surfaces and the product of the constant term and u^n corresponds to the coefficient of heat transfer k_h. The values of these constants are compared in the following tabulation.

	n	const. $(= k_h/u^n)$
Surface of fish muscle	0.77	1.65×10^{-8}
Water-saturated surface	0.80	1.67×10^{-8} [a]

[a] In the original reference (Jason, 1959), an error was made in the conversion from foot-pound-hour units to c.g.s. units which indicated a less satisfactory agreement.

Equation (9) is a useful empirical equation for calculating drying rates and is sufficiently accurate for most purposes. More detailed considerations (Powell, 1940), involving aerodynamic behavior in the vicinity of finite surfaces have been shown (Jason, 1959) to apply equally well to fish fillet pieces. Such considerations lead to an equation

$$\varepsilon\, l/(p_s - p_a) = 2.12 \times 10^{-7}\, l^{0.77}(l + 0.121\, u^{0.85}) \tag{11}$$

which represents the drying behavior of a plane surface of length l under conditions of streamlined flow.

The way in which the concentration of water at the surface C_s of a slab varies with time can be derived (Carslaw and Jaeger, 1947, p. 104) from Equation (2) and is expressed in the equation

$$C_0 - C_s = \frac{\varepsilon c}{D}\left\{\frac{Dt}{c^2} + \frac{1}{3} - \frac{2}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(\frac{n^2\pi^2 Dt}{c^2}\right)\right\} \tag{12}$$

C_0 being the initial concentration, assumed to be uniform throughout the slab of thickness $2c$.

Equation (12) breaks down when the rate of diffusion within the slab is insufficient to support the saturated condition at the surface and the concentration therefore rapidly falls to an equilibrium value C_e.

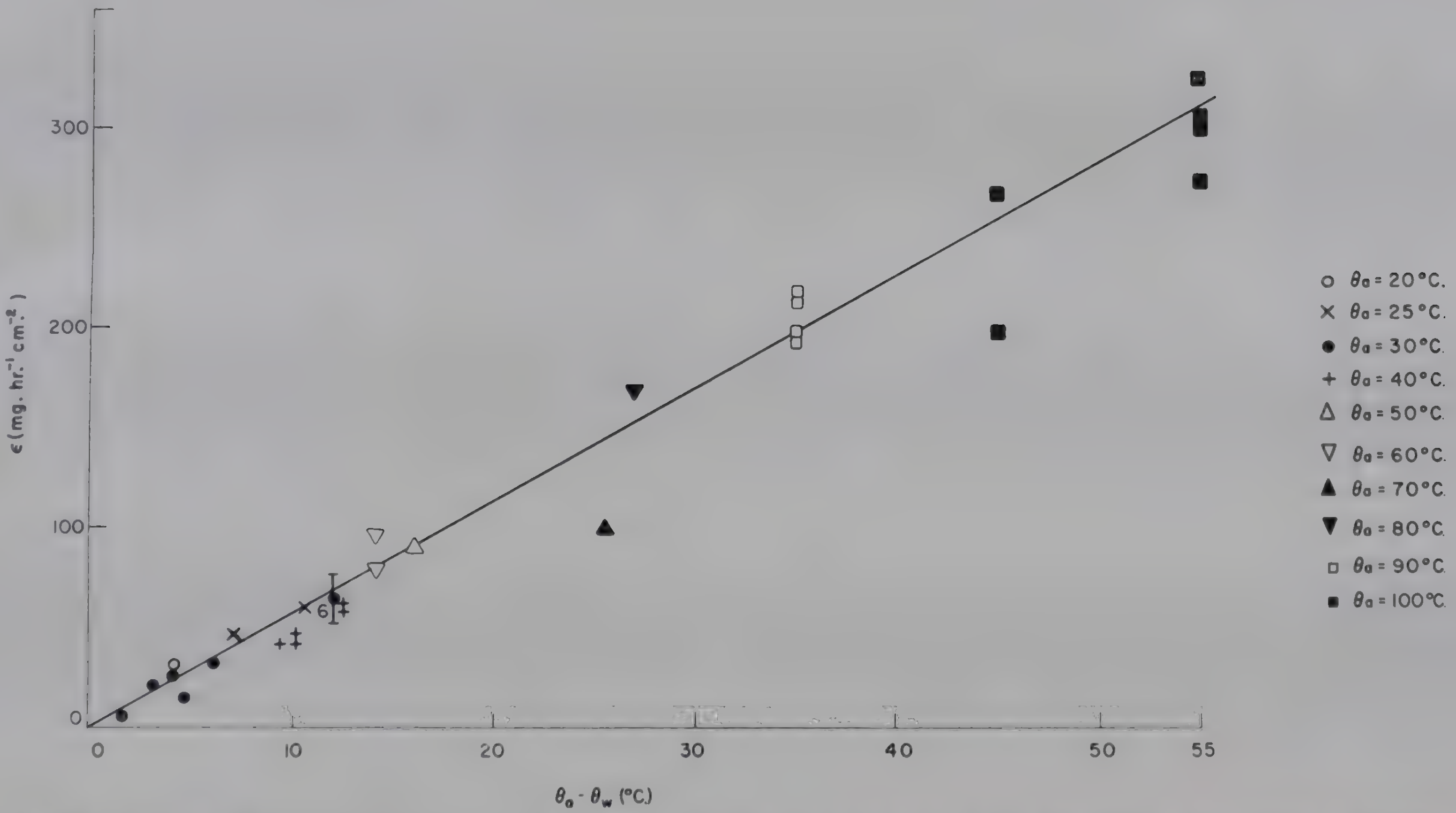


FIG. 5. Effect of wet-bulb depression on rate of drying per unit area of cod fillets exposed to air stream of velocity 366 cm./sec. at various dry-bulb temperatures. (Vertical bar through point and number indicate limits of standard deviation and number of determinations respectively where the latter exceed 4 determinations.)

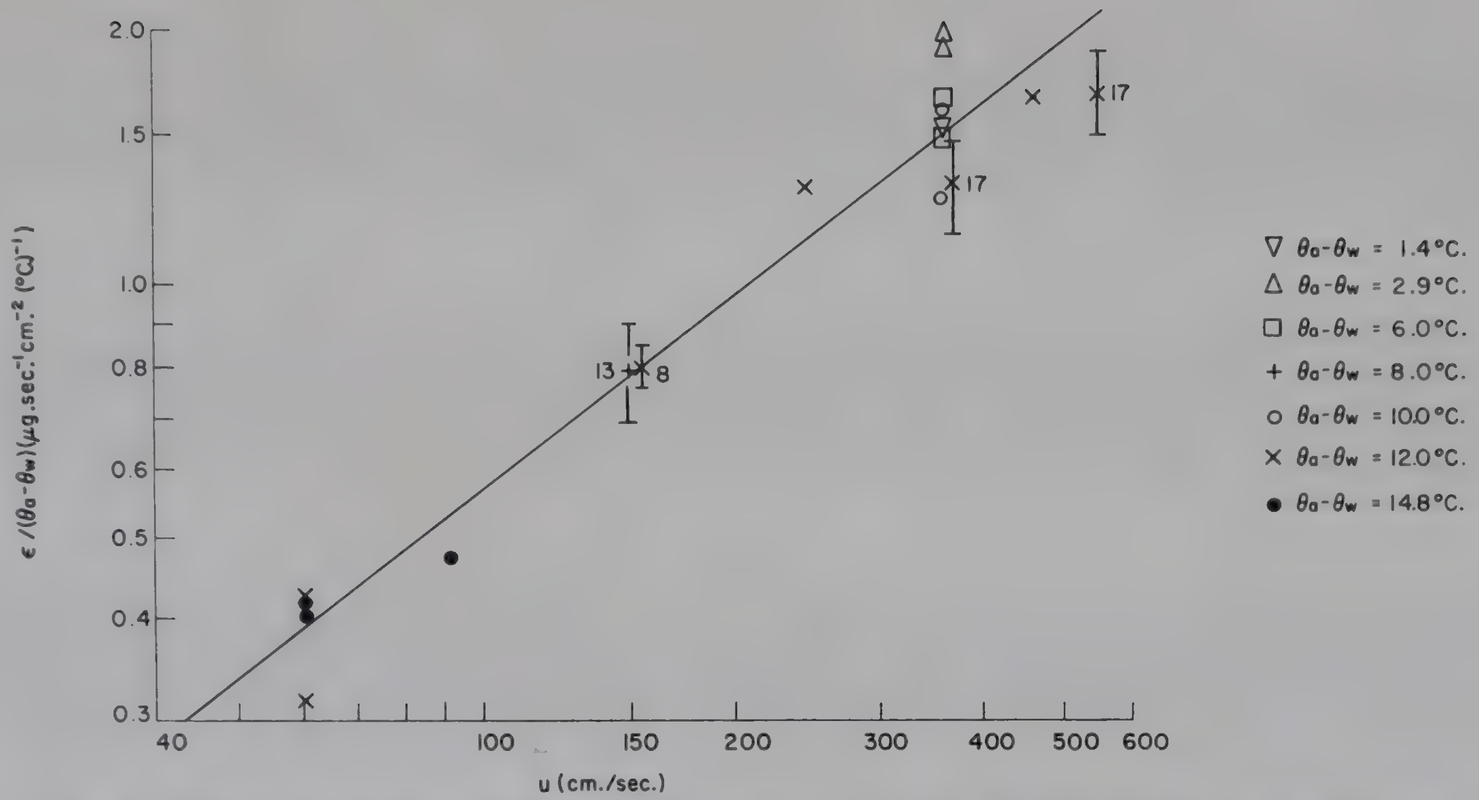


FIG. 6. Relationship between logarithm of rate of evaporation per unit wet-bulb depression and logarithm of air velocity for cod fillets. (Vertical bars through point and number indicate limits of standard deviation and number of determinations respectively where the latter exceed 4 determinations.)

This occurs at a time t_c, which may be called the *critical time*. Inserting these values into Equation (12) and rearranging gives

$$\frac{\varepsilon c}{D(C_0 - C_e)} = \left\{ \frac{Dt_c}{c^2} + \frac{1}{3} - \frac{2}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(\frac{n^2\pi^2 Dt_c}{c^2} \right) \right\}^{-1} \tag{13}$$

The left hand side of Equation (13) forms a dimensionless group $\varepsilon c/D(C_0 - C_e)$ which is a function of another dimensionless group Dt_c/c^2. This function has been plotted in Fig. 7 and may be used to derive the critical time for any given initial rate of evaporation, provided that the diffusion constant is known at the temperature θ_s. Figure 8 shows that there is good agreement between experiment and theory over a range of two orders of magnitude in ε.

The mean water content in a slab of a material at the critical time t_c is known as the *critical moisture content* (Perry, 1950) and is given by the expression

$$\frac{W_c - W_n}{W_n} = \frac{W_0 - (W_n + At_c)}{W_n} \tag{14}$$

where W_n is the weight of nonaqueous material contained in a total initial weight W_0, and where W_c is the total weight at $t = t_c$. It is clear that the value of the critical moisture content is not constant, as is frequently assumed, but varies with each of the parameters involved in Equation (13).

The drying behavior during the falling-rate period can be described by solving the Fourier equation and putting in the boundary conditions.

In a system of rectangular coordinates x, y, z, Equation (2) becomes

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} + D_z \frac{\partial^2 C}{\partial z^2} \tag{15a}$$

where D_x, D_y, and D_z respectively represent the diffusion coefficients along these axes.

But since it has been found that diffusion is practically isotropic in fish muscle (Jason, 1959) $D_x = D_y = D_z = D$ so that Equation (15a) may be written

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} \right) \tag{15b}$$

For the region

$$-a \leqslant x \leqslant a, \; -b \leqslant y \leqslant b, \; -c \leqslant z \leqslant c$$

i.e., for a slab of dimensions $2a$, $2b$, $2c$ (neglecting, for the moment, the existence of a constant-rate period) the boundary conditions are

(i) $C = C_0$ when $t = 0$
(ii) $C = C_e$ at $x = -a, a$; $y = -b, b$; $z = -c, c$
when $t > 0$

In other words, it is assumed that the water content at the surface attains its equilibrium value immediately drying commences.

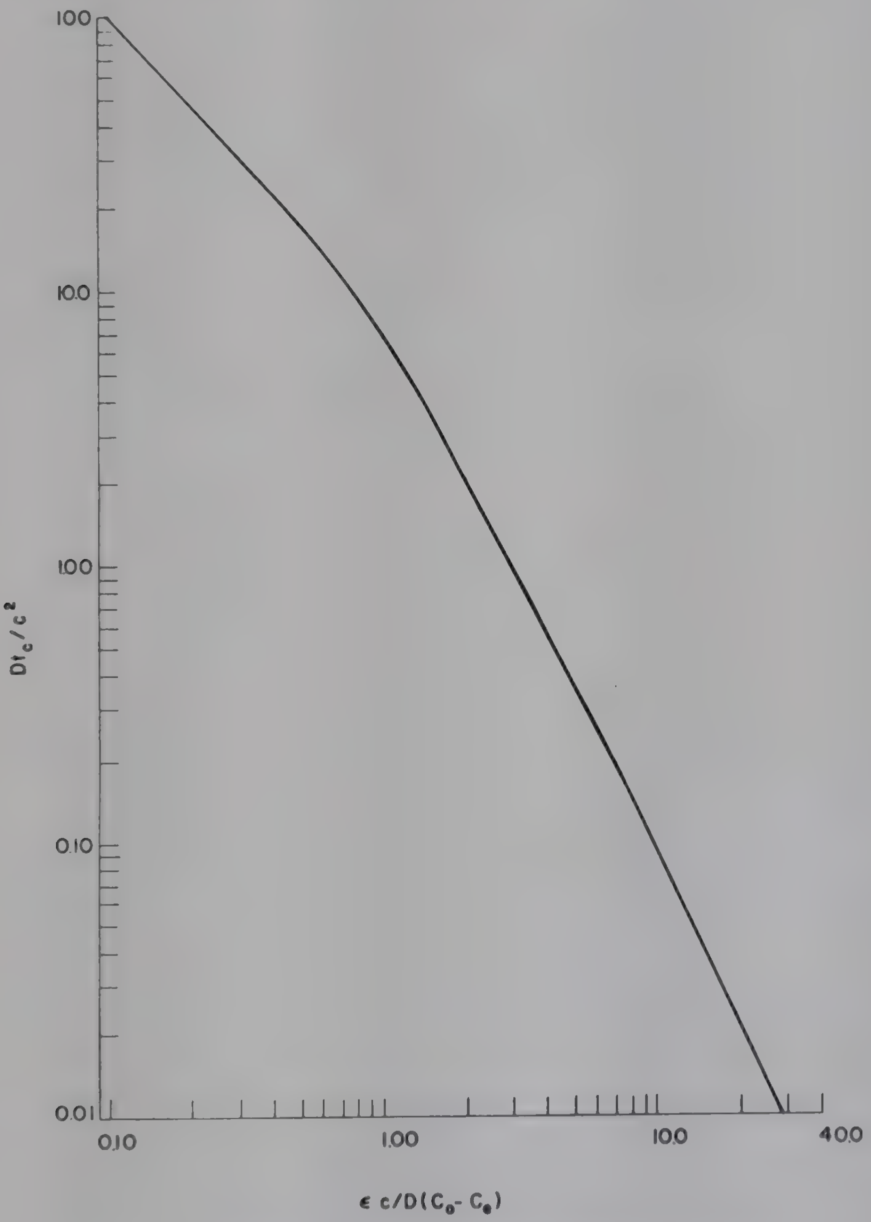


FIG. 7. $\varepsilon c/D(C_0 - C_e)$ as a function of Dt_c/c^2.

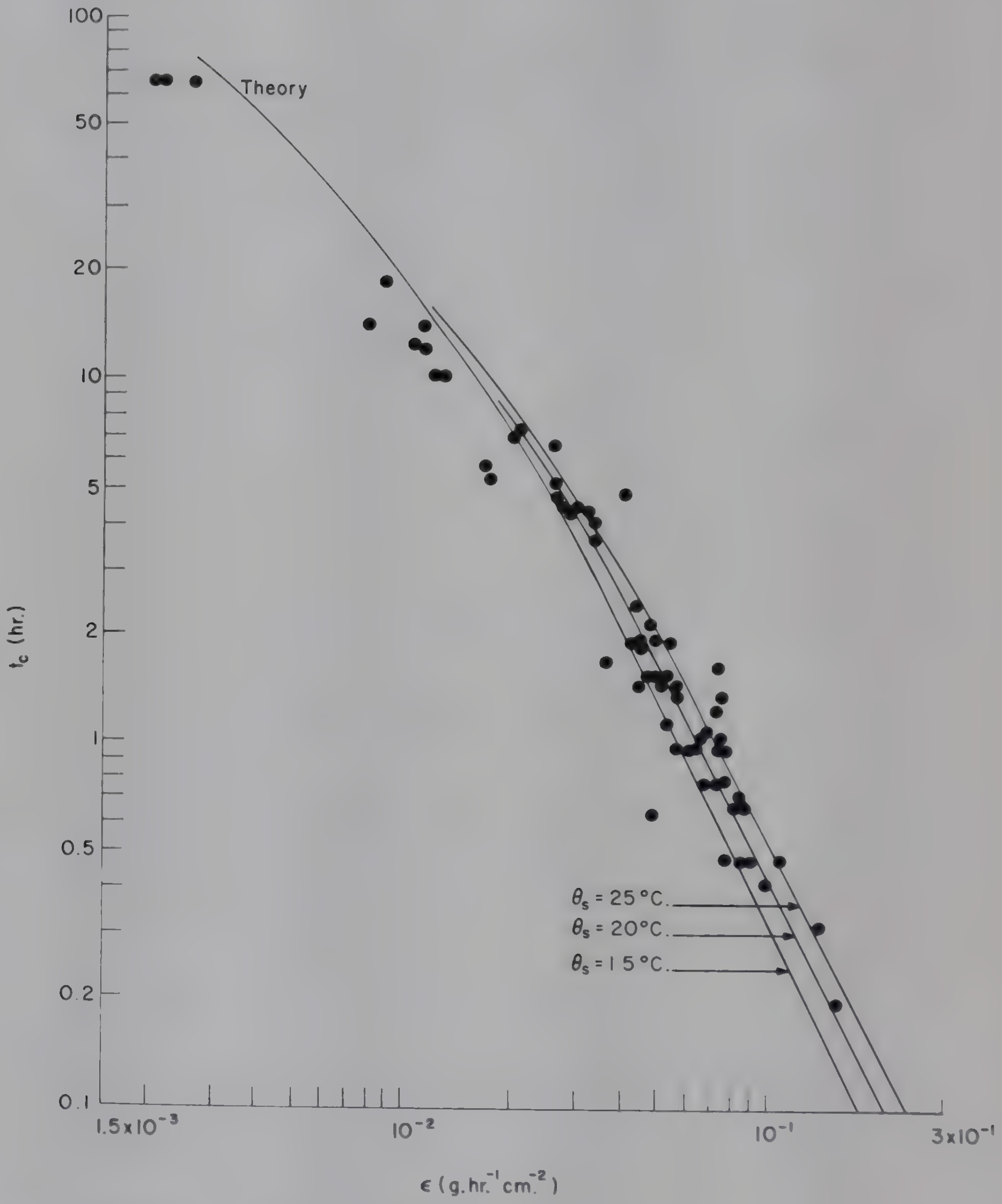


FIG. 8. Effect of rate of evaporation on duration of constant-rate period at $\theta_a = 30$°C. for cod fillet 0.5 cm. thick, showing theoretical curves for $\theta_s = 15°, 20°, 25°$C.

The solution of Equation (15b) has been given by Carslaw and Jaeger (1947, p. 163) as

$$C - C_e = \frac{64}{\pi^3}(C_0 - C_e) \sum_{l=0}^{\infty} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{(-1)^{l+m+n}}{(2l+1)(2m+1)(2n+1)}$$

$$\times \cos \frac{(2l+1)\pi x}{2a} \cos \frac{(2m+1)\pi y}{2b} \cos \frac{(2n+1)\pi z}{2c} \exp(-\alpha_{l,m,n} t) \tag{16}$$

$$\text{where } \alpha_{l,m,n} = \frac{D\pi^2}{4}\left[\frac{(2l+1)^2}{a^2} + \frac{(2m+1)^2}{b^2} + \frac{(2n+1)^2}{c^2}\right] \tag{17}$$

l, m, n being integers.

Equations (16) and (17), therefore, give the concentration of water at any point, x, y, z in a slab at any time t. The average concentration of water in excess of the equilibrium value is obtained by integrating Equation (16) over the whole volume of the slab and dividing by the volume. This gives an expression

$$\overline{C - C_e} = \left(\frac{8}{\pi^2}\right)^3 (C_0 - C_e) \sum_{l=0}^{\infty} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{\exp(-\alpha_{l,m,n} t)}{(2l+1)^2 (2m+1)^2 (2n+1)^2} \tag{18}$$

in which the series is rapidly convergent. For $t \gtrsim 1/\alpha_{l,m,n}$ all but the first term $(l = m = n = 0)$ may be neglected.

Now the unaccomplished weight loss at any instant is

$$W - W_e = 8abc\,(\overline{C - C_e})$$

so that Equation (18) becomes

$$\frac{W - W_e}{W_0 - W_e} = \left(\frac{8}{\pi^2}\right)^3 \exp\left[-\frac{\pi^2}{4} D \left(\frac{1}{a^2} + \frac{1}{b^2} + \frac{1}{c^2}\right) t\right] \tag{19}$$

A similar treatment may be given for a system of cylindrical co-ordinates r, θ, z in which the Fourier equation is

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r} + \frac{\partial^2 C}{\partial z^2}\right) \tag{20}$$

For a finite cylinder of radius a and length $2l$, the mean water concentration cannot be given explicitly as in Equation (18) for a finite slab. It is found, however, that for $t \gtrsim 4/\pi^2 D(a^{-2} + l^{-2})$, the unaccomplished weight loss is, in this case

$$\frac{W - W_e}{W_0 - W_e} = \text{constant} \times \exp\left[-\frac{\pi^2}{4} D\left(\frac{1}{a^2} + \frac{1}{l^2}\right) t\right] \qquad (21)$$

Although no species of fish can be represented by either a rectangular slab or a finite cylinder, most can be regarded as being of an intermediate shape. Unfortunately, solutions for intermediate shapes have not been worked out, because of the mathematical difficulties involved, but all will have the same exponential form as Equations (19) and (21), i.e.,

$$\frac{W - W_e}{W_0 - W_e} = \text{const.} \times e^{-t/\tau}$$

where τ has the dimension of time.

For a rectangular slab

$$\tau = 4/\pi^2 D\,(a^{-2} + b^{-2} + c^{-2}) \qquad (22a)$$

and for a finite cylinder

$$\tau = 4/\pi^2 D\,(a^{-2} + l^{-2}) \qquad (22b)$$

The quantity τ is termed the *drying time-constant* and its value characterizes the relative rate of drying of a given sample.

For values of $t > 0.2\tau$, an error of less than 2% is introduced by neglecting all terms in Equation (18) except the first. A plot of $\ln(W - W_e)$ against t will, therefore, be expected to give a straight line of slope $1/\tau$ for $t \gtrsim 0.2\tau$. In practice it is observed that the drying curve plotted in this way consists of two straight portions, the change of slope occurring at a moisture concentration of about 0.1 g. water per gram of non-aqueous material (Fig. 9). There are, therefore, two drying time-constants τ_{i} and τ_{ii} associated with each of these phases of the falling-rate period and corresponding to two diffusion constants D_{i} and D_{ii}, D_{i} being several times as large as D_{ii} in the range of temperatures normally obtaining. The transition between the two phases, which can be associated with the uncovering of the unimolecular layer of water covering the protein molecules, does not enter normally into most industrial processes, which fall within the bounds of the constant-rate period and the first phase of the falling-rate period.

Air velocity and relative humidity have no influence on the rate of diffusion of water in fish muscle, and, therefore, on the rate of drying during the falling-rate period, except insofar as they affect the temperature of the muscle. Relative humidity will, however, affect the equilibrium water content.

Temperature has considerable influence on the rate of drying because the diffusion coefficient depends on the thermal energy of the water molecules. The variation of both D_i and D_{ii} with absolute temperature T is the form

$$D = D_0 \exp(-E/RT) \tag{23}$$

where D_0 is a constant, E is the energy of activation for diffusion, and R is the gas constant. For cod muscle the values of D_0 and E for the first

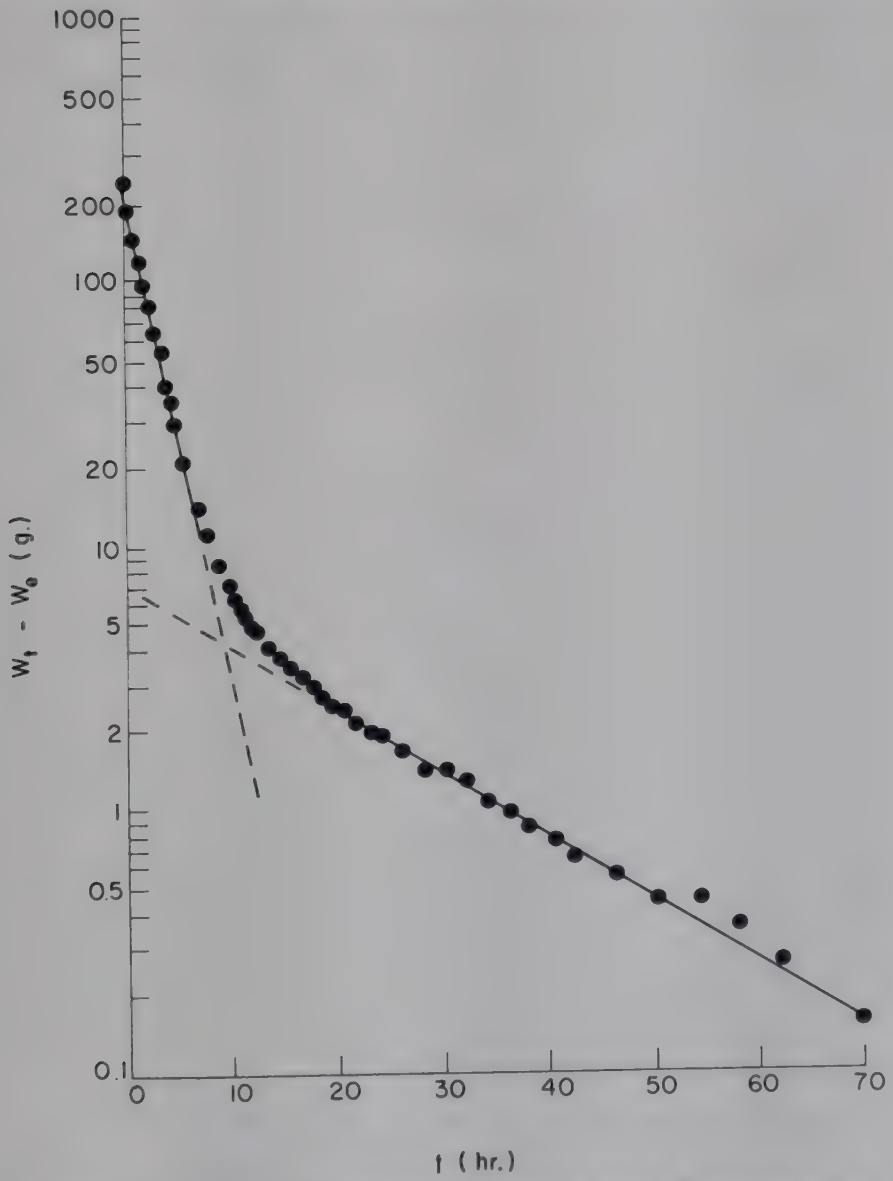


FIG. 9. Logarithm of unaccomplished weight loss in cod fillet piece 10 × 5 × 0.6 cm.^{3} as a function of time. Dry-bulb temperature 35°C.; wet-bulb temperature 20.3°C.; air velocity 366 cm./sec.

phase are 0.54 cm.^{2}/sec. and 7200 cal./mole, and for the second phase the corresponding values are approximately 0.7 cm.^{2}/sec. and 8500 cal./mole. The energies of activation differ significantly but the D_0 values do not.

Values of D_{i} are approximately the same for all species of nonfatty fish; for fatty fish, the diffusion constant decreases with increasing fat content. Similar observations apply to D_{ii} values which are in general approximately one-fifth of the D_{i} values irrespective of fat content.

For practical calculations of the weight of a piece of fish at any given time, certain approximations must be made. The movement of water in flat fish, split fish, or fish fillets can be regarded as being normal to the surface, as in the case of an infinite slab, and the effective half thickness c_{eff} is therefore obtained from the half thickness c_{i} measured at each of r equally spaced points; thus

$$c_{\text{eff}} = \left(\frac{1}{r} \sum_{\text{i}=1}^{r} \frac{1}{c_{\text{i}}^2} \right)^{-1/2} \tag{24a}$$

If whole round fish are regarded as being cylindrical in shape, the effective radius a_{eff} is likewise obtained from measurements of radii a_{i} in equally spaced transverse sections, thus

$$a_{\text{eff}} = \left(\frac{1}{r} \sum_{\text{i}=1}^{r} \frac{1}{a_{\text{i}}^2} \right)^{-1/2} \tag{24b}$$

The procedure is then to calculate the rate of evaporation per unit area for the appropriate drying conditions from equation (10) and to obtain the duration of the constant-rate period from Fig. 7.

Thus the unaccomplished weight loss $W_c — W_c$ at the critical time is derived from the rate of evaporation and the equilibrium water content (obtained from the appropriate vapor pressure isotherm).

In most cases, even though the duration of the constant-rate period is significant, the drying curve is exponential for $t > t_c$ because the higher order terms in the solution of the Fourier equation are rapidly damped out. Thus, during the first part of the falling-rate period

$$W — W_e = (W_c — W_e) \exp [—(t — t_c)/\tau] \tag{25}$$

The following is a worked example for a cod fillet piece 10 × 5 × 1.46 cm.^{3} dried at 30°C. in an air stream of velocity 150 cm./sec. and wet-bulb depression 12°C. Initial weight of piece = 73.1 g.; equilibrium weight = 14.4 g.

During the constant-rate period

$$\varepsilon = \frac{1}{A}\,\frac{dW}{dt} = 1.65 \times 10^{-8}\,(\theta_a - \theta_w)\,u^{0.77} \times 3600$$

$$= 33.6 \times 10^{-3} \text{ g./hr.}$$

$$\therefore\ t_c = 3.6 \text{ hr. (experimental value 3.5 hr.)}$$

$$\frac{dW}{dt} = 33.6 \times 10^{-3} \times 144$$

$$= 4.84 \text{ g./hr. (experimental value 4.7 g./hr.)}$$

Now

$$(W_c - W_e) = (73.1 - 3.6 \times 4.84) - 14.4$$

$$= 41.3 \text{ g.}$$

$$\text{and } \tau = 15.9 \text{ hr. (experimental value 16.9 hr.)}$$

Table VII compares calculated and observed values of W for various values of $t - t_c$.

TABLE VII

CALCULATED AND OBSERVED VALUES OF W FOR VALUES OF $t - t_c$

$t - t_c$ (hr.)	Calculated weight, W (g.)	Observed weight, W_{obs} (g.)
0	55.7	57.6
2	50.9	51.8
4	46.1	46.2
6	42.8	42.3
8	39.4	39.4
10	36.4	36.7
15	30.5	30.2
20	26.1	26.4
25	23.0	23.4
30	20.7	21.1

E. PHYSICS OF VACUUM FREEZE-DRYING

A large part of the water incorporated in the tissues of food separates in the form of pure ice crystals when the food is frozen. The remainder of the water is contained in solutions of salts and sugars (which do not freeze out until the appropriate eutectic points are reached), and in the monomolecular layer adsorbed on the nonaqueous material. The ice and (less readily) the water contained in solution are free to evaporate. Water in the monomolecular layer is slow to evaporate at the temperatures here under consideration.

If the food is placed in a vacuum chamber and the pressure is reduced to a negligible value, the initial rate of drying is, ideally, given by equation (1). Unfortunately, several factors combine to prevent such a high rate from being achieved in practice. First, there is evaporative cooling at the surface which immediately reduces the saturation vapor pressure of the ice. Secondly, the specific volume of water vapor at the temperature of the surface is so great that no pump can cope with the rate of flow, and the total pressure will, therefore, rise rapidly toward an equilibrium value. Thirdly, once the ice at the surface has evaporated, water vapor from within the material must diffuse through a resistive porous layer of dry material formed by the crystallization and subsequent evaporation of ice. This resistive effect becomes greater as the ice surface recedes, and at pressures of the order of 1 mm. Hg or less, such resistance within the material is greater than that encountered by the vapor in being removed from the vicinity of the material.

If, in order to replace the latent heat of evaporation, the surface of the food is heated by some means, the rate of drying will depend on the amount of heat which is conducted through the porous layer as shown by Equation (3). As the thickness of this layer increases, the resistance to heat conduction increases and so the rate of drying falls off.

A detailed treatment of the theory of freeze-drying of frozen tissues has been given by Stephenson (1953). A substantially similar, though more concise, presentation by Harper and Tappel (1957) enables the treatment to be applied more readily in practical calculations because the parameters involved are in a form more easily obtainable experimentally. The theory of Harper and Tappel is in every way applicable to fish muscle and will now be briefly presented.

Darcy's law states that the velocity of flow of a fluid through a porous medium is proportional to the pressure gradient and inversely proportional to the viscosity of the fluid, thus

$$u = -\frac{K}{\mu} \cdot \frac{dp}{dx} \tag{26}$$

where u is the velocity, μ the viscosity, and dp/dx the pressure gradient. The symbol K represents a constant of proportionality, the permeability constant. For isothermal flow of a perfect gas through a medium of constant cross-sectional area, the rate of flow per unit area is obtained from Equation (26) by integration. Thus

$$\frac{dm}{dt} = \frac{KM\Delta p\, p_m}{\mu x RT} \tag{27}$$

where dm/dt = mass rate of flow per unit area; M = molecular weight; x = length of flow path; Δp = pressure drop over flow path; p_m = arithmetic average of terminal pressures; R = gas constant; T = absolute temperature.

Under conditions normally obtaining in vacuum freeze-drying, the effects of mean free path on the water vapor molecules cannot be ignored, and the right-hand side of equation (27) must be modified by introducing a term which depends both on the mean free path λ and on K. Equation (27) may therefore be written in a simplified form as

$$dm/dt = (a/x)\,\Delta p\,(p_m + b) \tag{28}$$

where

$$a = KM/\mu RT \text{ and } b = \text{constant } \lambda^{0.8}\,K^{-1/2}$$

A system is now considered in which an infinite slab of frozen material of uniform thickness is heated from both surfaces in an evacuated enclosure. It is postulated that the vapor is free to escape through each surface and that the resistance to the removal of vapor from the enclosure is negligible in relation to the resistance of the porous material.

Under these conditions the rate of heat transfer through the layer of dried material, of unit cross-sectional area and thickness x, is

$$\frac{dH}{dt} = \frac{k\,(\theta_s - \theta_i)}{x} \tag{29}$$

where k = thermal conductivity of dried material; θ_s = temperature of surface of dried material; θ_i = temperature of ice surface. The rate of heat transfer must equal the product of the mass flow rate and the latent heat of evaporation (or sublimation) L. Thus, from Equation (28) and (29)

$$\frac{k\,(\theta_s - \theta_i)}{x} = \frac{La\Delta p}{x}\,(p_m + b) \tag{30}$$

Since x cancels, the temperature-pressure relationship is independent of the extent of drying. Provided that the vapor pressure of the ice is considerably greater than that at the surface of the material, it is evident that both Δp and p_m depend essentially on the former. Since the vapor pressure of the ice varies only with θ_i there is a unique value of θ_i for a given value of θ_s.

Now the flow rate per unit cross section may be written

$$dm/dt = (C_0 - C_e)\,dx/dt \tag{31}$$

where C_0 and C_e are respectively the initial and equilibrium concentrations of water per unit volume. Equating this value of m with that given by Equation (28),

$$dt = \frac{(C_0 - C_e)}{a\Delta p\,(p_m + b)}\, x\, dx \tag{32}$$

Thus, the time taken to dry a slab of thickness $2c$ from both sides is

$$t = \int_0^c \frac{(C_0 - C_e)}{a\Delta p\,(p_m + b)}\, x\, dx = \frac{(C_0 - C_e)}{a\Delta p\,(p_m + b)}\, \frac{c^2}{2} \tag{33}$$

or, by combining equations (30) and (33),

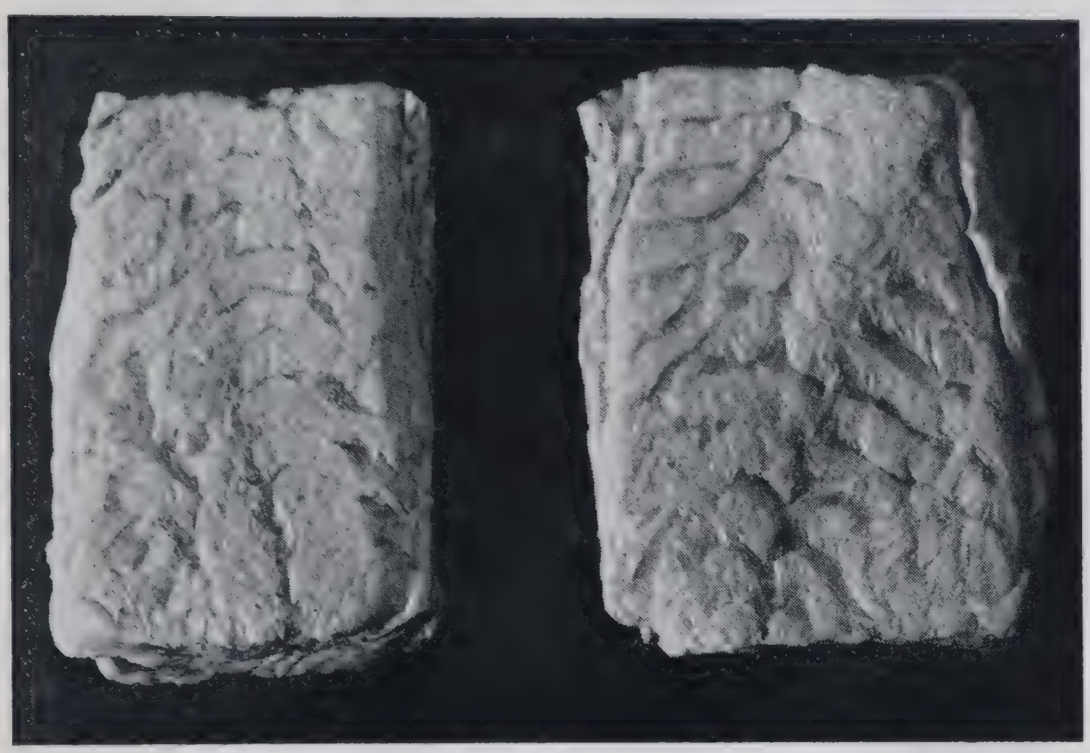
$$t = \frac{L\,(C_0 - C_e)}{k\,(\theta_s - \theta_i)}\, \frac{c^2}{2} \tag{34}$$

The drying time for a given thickness may, therefore, be calculated either from measurements of chamber pressure and ice temperature (to give p_m and Δp) if the parameters a and b are known, or from known values of L and k combined with measurement of $\theta_s - \theta_i$.

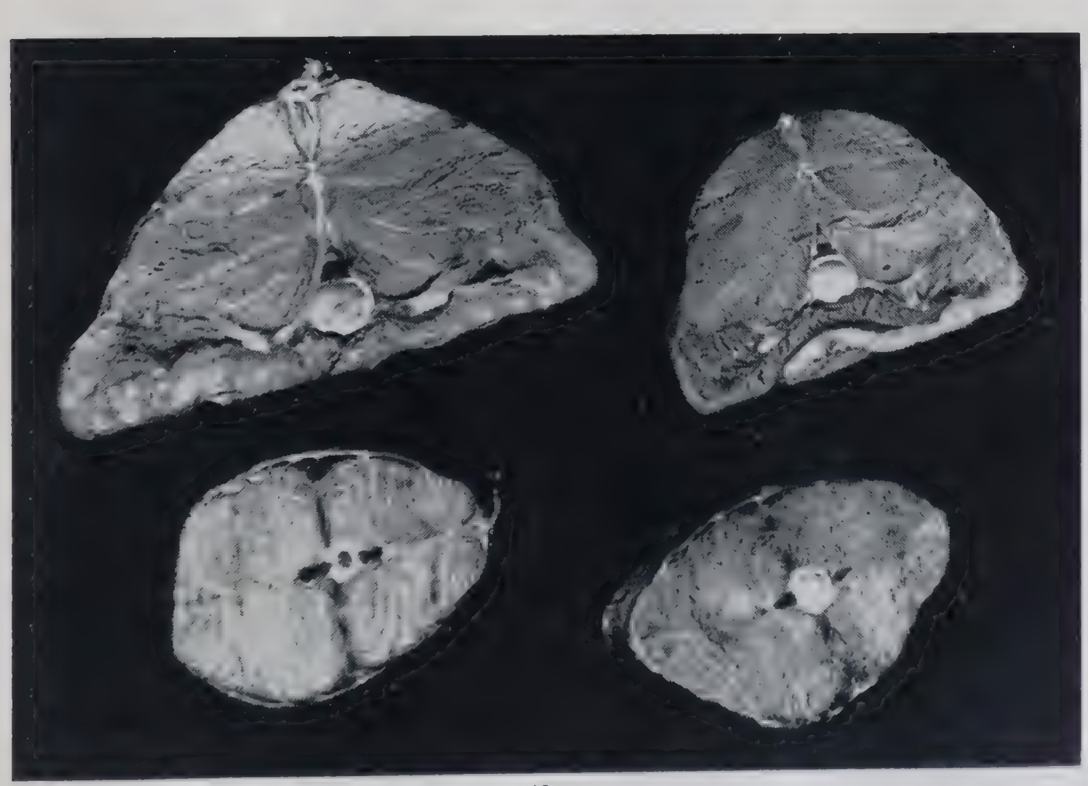
Equations (33) and (34) show that for rapid vacuum freeze-drying it is desirable to have the following conditions:

a. Maximum permissible ice temperature compatible with material remaining frozen (in order that both p_m and Δp should be as high as possible).
b. Low chamber pressure in relation to vapor pressure of ice.
c. High permeability constant.
d. High thermal conductivity.
e. Maximum permissible surface temperature without producing thermal damage to material.
f. Thin slabs of material.

Conditions *a* and *b* are interdependent and are affected by the permeability and thermal conductivity. The permeability constant (and, to a lesser extent, the thermal conductivity) are not invariant quantities. For example, the effect of ultrarapid freezing is to produce only diminutive channels, and hence a low permeability of freeze-dried tissue results. Very slow drying is predicted for fish so frozen. Furthermore, as will be observed in Fig. 10, the structure of freeze-dried fish is markedly anisotropic, there being a pronounced tendency for channels to form parallel to the direction of the muscle fibers, which are themselves generally arrayed longitudinally in the fish. For this reason K is greater for steaks or cutlets (i.e., sections cut transversely to the sagittal section) than for fillets, and the former are expected, from Equation (33), to dry more rapidly than fillets of the same thickness. Although k, too, might be expected to differ in the two types of section, rough measure-



(a)



(b)

FIG. 10. Gross structure of freeze-dried cod muscle; *a*: sagittal sections and *b*: transverse sections. (By kind permission of Ministry of Agriculture, Fisheries and Food.)

ments by the writer show that such a difference, if it exists at all, is relatively small. If this observation is correct, then the product $t(\theta_s - \theta_i)$ in Equation (34) will be constant for each type of section. Experimental values (Jason, 1960) given in Table VIII for pieces of cod 15 mm. thick dried at a total pressure of 1–3 mm. Hg and heated from one side only show that this product is, in fact, approximately constant. In these determinations, θ_s represents the temperature of the heated plate on which the pieces were supported and t is the time required to dry to a weight loss of 80%

TABLE VIII

EXPERIMENTAL VALUES OF θ_s, θ_i, t FOR COD MUSCLE FILLETS AND STEAKS 15 MM. THICK

Type of section	θ_s (°C)	θ_i (°C)	t (hr.)	$t(\theta_s - \theta_i)$ (hr. × °C.)
Fillet	0	—22	80	1720
	0	—23	80	1840
	45	—20	30	1950
	75	—16	17	1547
Steak	75	—15	13½	1215
	75	—16	12½	1138
	75	—18	13½	1256

Remembering that in Equation (28) $a \propto K$ and that values of Δp, p_m, b and k are roughly the same for each type of section, it is clear from Equation (34) that the products $t(\theta_s - \theta_i)$ are approximately inversely proportional to the ratio of the respective values of K. It would appear, therefore, that in this series of determinations on cod muscle, $K_{\text{cutlet}}/K_{\text{fillet}} \cong 1.46$.

III. Practical Aspects of Fish Drying

A. NATURAL AIR DRYING

Although no doubt total world production of dried fish is considerable, the recorded statistics are unreliable and represent only a fraction of what is actually made.

In Norway and Iceland, stockfish is made by drying unsalted cod in the open air during the spring, before flies become a nuisance. This dried product is made in Scandinavia into a dish called *lutefisk* by soaking it in alkali before cooking. Various dishes made from stockfish are also popular in Mediterranean Europe. Nevertheless, much of the dried fish, especially lower grades, is exported to Africa and South America. For example, a thriving trade with Nigeria in "Afrika fisk" has sprung up since about 1912.

The procedure adopted is still much the same as it was in the Middle Ages when stockfish was a staple article of diet throughout Europe (Cutting, 1955). The fish are simply beheaded and cleaned, tied in pairs by the tails and hung on a drying rack consisting of smoothly planed poles which rest on stout beams. Drying takes two to six weeks, depending on weather conditions and the size and thickness of the fish. The final water content is about 16%, at which mold growth is practically suspended. Large fish are split by cutting close to the bone so that they hang practically in two pieces except for a small piece near the tail, which serves to suspend the fish on the rack (Jarvis, 1950). In Norway, meteorological conditions are only suitable for drying stockfish in the spring and in a certain zone north of Ålesund. If the temperature is too high, the fish goes bad before it can be dried sufficiently to preserve it.

Iceland, associated with stockfish since the fifteenth century, is once again a considerable producer.

Although fatty fish, such as herring, do not so easily lend themselves to preservation simply by drying alone, such products, made chiefly for local consumption, are met with throughout the world from Iceland to Japan. In some Japanese products it seems possible for the temperature of the flesh to reach 30°C. during drying (Maruichi and Hino, 1957). In Africa, drying is often effected by means of fires and the resultant products are partly barbecued, partly hot-smoked like the "bonga," produced from a fish similar to a small horse mackerel.

The production of split, salted cod was, until recent times, the most widely practised process of natural air drying. After wet stacking, the moisture content of between 55 and 60% is reduced to between 30 and 45%, depending on the product and the market, by successive processes of exposure to sun and wind, usually on frames, termed "flakes" in North America, and press-piling to homogenize the product for further drying. In the past 30 years or so, this natural drying has generally given way to "artificial" driers.

B. Wind Tunnels

Even before 1900, a number of devices involving the use of heat, dry air, and even absorption pads, had been invented in North America for drying salt fish to overcome difficulties and uncertainties caused by the weather (Wood, 1951). The most persistent of these was a warm-air drying process patented by Thomas S. Whitman of Annapolis, Nova Scotia, which was still being used by at least one plant in Canada as recently as 1946. However, even by 1936 these driers were realized to be inefficient and rather difficult to control. About this time the drying of heavily salted fish began to be studied by government scientific research workers in Canada, Newfoundland, and Norway, with a view to establishing the optimum conditions of temperature, relative humidity and air velocity as a basis for the rational design of drying plant.

According to the Canadian results (Linton and Wood, 1945), the optimum air velocity over the fish should be between 200 and 300 ft. per minute. Slower velocities decrease the rate of drying, while faster velocities do not increase it appreciably and merely add to the power costs. Air temperature should be between 60° and 80°F. (16° and 27°C.) and preferably about 75°F. (24°C.). The relative humidity (R.H.) of the air in the drier should be between 45 and 55%; above or below this, drying is slower. Above 76% R.H., salt fish absorbs moisture (Cooper, 1938). Slow drying at the beginning results in the formation of undesirably rough and pebbly crystals of salt on the surface. Under the optimum conditions specified above, the rate of drying decreases steadily for the first six to ten hours. By this time the surface has dried to form a salt crust, and drying then proceeds at a constant rate by evaporation underneath the surface. Stacking at this stage wets the crust so that the rate of drying is increased until the surface layer is reformed. Hand-dried salt cod for export can be produced in about 40 hr. by this method.

Driers of various patterns designed to reproduce the above conditions have been widely installed in Canada (Cooper, 1942; Weisselberg, and Weisselberg, 1944).

In Britain the driers in use are mostly of the older type. One of the most popular patterns, designed about 1930 and still largely used, consists of a tunnel 85 ft. long and 6 ft. high holding 8 tons of fish on hooks on 64 trucks, which pass on rails along the length of the tunnel in one direction and return in the opposite direction. A 10-H.P. motor drives the fan, the heater uses 2 gallons of oil fuel per hour, and the drying is reckoned to take 4 days.

C. Roller Drying

Apart from the patent by Townsend (1922), which does not appear to have been developed commercially, the roller drying of fish was investigated experimentally by Cutting *et al.* (1956, pp. 13–15). Minced, cooked fish came off the rollers in a continuous lacework of flattened fibers which, on restoration of the water, gave an impression of texture to the palate somewhat resembling that of freshly cooked fish. However, on the experimental scale constant attention was required in order to deliver fish from the rollers uniformly dry.

D. Warm Air-Tray Drying of Minced Fish

It was this process which, as mentioned in Section I, was developed on a pilot scale in the United Kingdom in World War II (Cutting *et al.*, 1956).

1. *Raw Material*

Practically any type of fish can be employed, even fatty fish such as herring, although elasmobranch species, such as dogfish, sharks, and skate, which contain 1% or so of urea, develop a slight ammoniacal odor and flavor on storage. However, to minimize oxidation of fat as well as for bacteriological reasons, reasonably fresh fish should be used and should be handled expeditiously all along the processing chain for the most acceptable product.

2. *Initial Preparation and Cooking*

Fish are first washed thoroughly to remove dirt, slime, and scales, and then beheaded, skinned when possible, and filleted, leaving only the flesh. This is cooked either as fillets or minced, on perforated metal trays in a live steam retort at a pressure of about 2 lb. per sq. in. for about 30 min. In this process some 20 to 40% by weight escapes in liquor consisting mostly of water, although containing some protein and other nutrients.

3. *Tray Spreading*

Particular care is needed at this stage in order to obtain a dried product of agreeable texture. The best results were obtained by mincing the cooked fish after it was cool using ⅜- to ½ in.-diameter holes. This material was then spread lightly and uniformly by hand and raked onto wire mesh trays at a density of 2 lb. per sq. ft., so that a porous, more or less particulate structure was presented to the air during the actual drying. If the material was pressed down at all heavily, it took longer to dry, and the product was tougher and more difficult to reconstitute. For this reason, pressing after cooking to remove some of the water was found to yield an unsatisfactory product. The drying of fish flakes, too, gave a rather tougher product than a dry, carefully produced and handled mince.

4. *Drying*

The drier used in the wartime pilot plant experiments was based on the Torry mechanical fish-smoking kiln (Cutting, 1950). The drying trays were spaced at 2½-in. intervals and air was blown over them at 10 to 15 ft./sec. The temperature was initially 80° to 85°C. (176° to 185°F.) and was lowered to 65° to 70°C. (149° to 158°F.) by the end of the drying process. The relative humidity was also controlled at a value corresponding to a wet-bulb temperature of above 50°C. (122°F.) for the first hour, so as to prevent multiplication of bacteria. As the material dried, its temperature rose until it approached dry-bulb temperature. Drying from a moisture content of about 2.7 g. per gram of dry, fat-free solid down to 0.1 g. per gram took about 4 hr. for white fish and an hour or so longer for fatty fish, depending on the fat content.

5. *Packing and Storage*

Packing in cans filled with nitrogen gave the best storage properties. Compression was satisfactory if carried out at a water content of about 10% so that the product was not brittle enough to be pulverized. Storage life was very dependent on temperature, varying from several years at 10° to 15°C. (50° to 68°F.) to only a few months at 37°C. (98°F.). It did not seem to be affected by moisture content within the range 2 to 12%, although not all workers are in agreement on this.

E. VACUUM FREEZE-DRYING

In Section 2,E above, desirable conditions were listed for rapid freeze-drying. From these, it is immediately obvious that on a commercial scale an extension of the normal laboratory method of freeze-drying is impracticable because high rates of heat transfer are required. Clearly, a load of fish supported *en masse* inside a vacuum chamber would receive practically no heat (except on those surfaces receiving radiation from the walls of the chamber) and most of it would cool by evaporation until no further drying took place.

The simplest method of providing the necessary heat is to support the fish on heated trays, and for most small-scale purposes this is perhaps adequate. However, the heat transfer coefficient between the trays and the fish is not normally great enough to permit the achievement of economically high drying rates.

F. VACUUM CONTACT DEHYDRATION[2]

Fish was first dried on a commercial scale in a vacuum by the Danish "Pressfisk" process (Hay, 1955). The equipment (Fig. 11) consisted of a chamber of rectangular section containing 24 horizontal mild steel heating plates grouped in three banks, one above the other, with 8 plates per bank, each bank thus accommodating 7 trays of material. In this way, batches of up to 1 ton of raw material could be processed per run. Heat was supplied by hot water circulating in the hollow heating plates. In order to maintain thermal contact between the plates and the fish as the fish shrank during drying, the plates were made to close progressively by a hydraulically actuated lever mechanism. The chamber was evacuated by means of two steam augmenters backed by two water ejectors, and the pressure ranged approximately from 15 down to 2 mm. Hg as drying proceeded.

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[2] The writer is indebted to Mr. J. C. Forrest of the Experimental Factory, Ministry of Agriculture, Fisheries and Food, Aberdeen, Scotland, for assistance in the preparation of this and the following subsection.

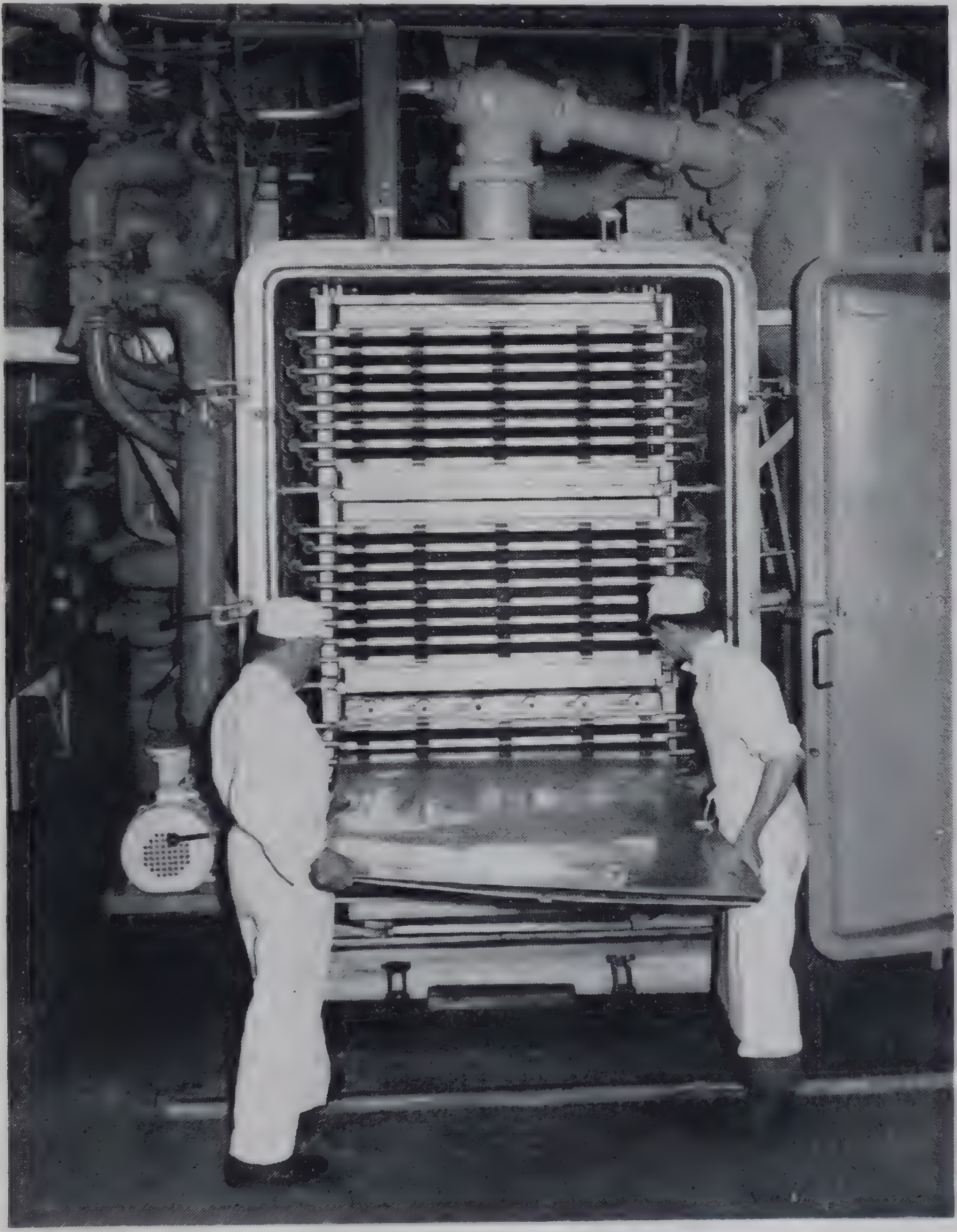


FIG. 11. Large vacuum chamber for drying fish showing arrangement of heated plates. (By kind permission of Ministry of Agriculture, Fisheries and Food.)

Because the water-vapor pressure in the system was always greater than the vapor pressure of ice at the initial freezing temperature of fish (—1.1°C.) freeze-drying could not take place. Although shrinkage occurred during drying, the product was nevertheless somewhat porous. The time taken to reduce the moisture content of the fish down to 15% was about 7 hr. At this stage the mat of fillets was removed from the chamber, cut up into a suitable shape, compressed by means of a hydraulic ram, and subsequently dried *in vacuo* to a moisture content of about 5% (dry weight basis).

The method suffered, among other things, from the disadvantage that reconstitution was very slow compared with that of freeze-dried fish and was by no means complete after many hours of soaking in water. Even then the texture tended to be tough and stringy (Hanson, 1959).

Despite the apparent disadvantages of the original "Pressfisk" process, there was promise of improvement when the then British Ministry of Food decided in 1948 to subject the method to intensive investigation. Workers in the Ministry's Experimental Factory in Aberdeen later modified the process (Hay, 1955).

It was found that compression of the dried product led to a marked reduction in the rate of reconstitution so that, despite the implications for storage and transportation, debulking had to be abandoned. In order to improve both the reconstitution properties and the quality, many variations in the pretreatment and post-treatment of the fish were devised. It was ultimately found possible, by a method consisting essentially of an alkaline dip before drying, to obtain a product which would reabsorb water over a period of an hour or two. However, the fish had by then lost its characteristic texture and would not reconstitute to anything like its initial moisture content. It was, therefore, far from having the desirable qualities of freeze-dried fish—retention of nutrients, appearance, flavor and texture, and rapidity of reconstitution.

At this stage, improvements in the ejector system enabled the operating pressure in the chamber to be reduced to about 1 mm. Hg, and it was then found possible partly or completely to freeze-dry the fillets. It had earlier been found that variations in the thickness of layers caused wide discrepancies in the final moisture content at different points in the material, the thinner portions drying more slowly as a result of poor thermal contact. A special flat-cutting machine (Hay, 1955) was developed to cut oversize fillets down to a uniform maximum thickness, and when this was used to prepare fish for the drying plant, freeze-drying could be achieved consistently, uniformly and more rapidly than was previously possible.

The speed of drying was further increased by cutting fish flesh across the fibers, since the resistance to vapor flow is less in the direction parallel to the fibers than in a transverse direction. The fish was first frozen and cut into steaks of uniform thickness and then loaded, still frozen, into the drier. By means of this procedure, fish steaks 17 mm. thick were dried in 10½ to 11 hr. This process is known as the VCD method.

G. Accelerated Freeze-Drying

The advantages of the VCD method over conventional shelf drying is that heat is conducted into material through top and bottom surfaces simultaneously, and better thermal contact can be maintained between the heated plates and the fish. In principle, this should lead to a rate of drying considerably in excess of double the rate of shelf drying. However, the close contact between plates and fish produces a high resistance to vapor flow, and this "stifling" effect tends to offset the advantage of good thermal contact. The mutually conflicting requirements of maximum heat flow and minimum resistance to vapor flow cannot be satisfactorily resolved. Excessive heat transfer coupled with a low vapor escape rate can result in thawing, and the fish suffers damage in consequence.

Recently, considerable improvement was effected (Dalgleish and Thompson, 1958) by introducing an innovation which largely removes this difficulty. If a piece of expanded aluminum sheet is placed between product and heating plate on the top and bottom surfaces (Fig. 12), a series of channels is formed, separated by the mesh formation. The channels provide an escape path for the water vapor, thus markedly reducing the resistance to flow, while the mesh itself, being in good contact with the material, assures an adequate flow of heat to the surface of the fish. Moreover, since the points of the expanded sheet form indentations on the surface, some penetration of the dry layer of material is achieved. Using this equipment, the drying time for 15-mm.-thick cod steaks is reduced from 10½ or 11 hr. to 6½ or 7 hr. Figure 13 compares the temperature behavior of fish and heating plates in the VCD process with that of the accelerated freeze-drying (AFD) process. The temperature deep within the material reflects the approach of the end of drying, and when this temperature reaches that of the water in the heating plates, drying can be assumed to be complete.

The application of heat from both sides of the material, coupled with the effect of expanded metal trays on heat transfer and vapor flow, has so increased the initial rate of drying that the removal of water vapor from the vacuum chamber is now a limiting factor at the commencement of the process. (It is estimated that the augmenters pump water vapor at the rate of about 86,000 liters per second at a pressure of 1 mm. Hg when the initial charge is one ton of fish.) Even so, if some means could be found of maintaining the initial rate of heat transfer to the ice throughout the drying period, such a rate of pumping would result in complete drying of 15-mm.-thick cod steaks in less than 2½ hr.

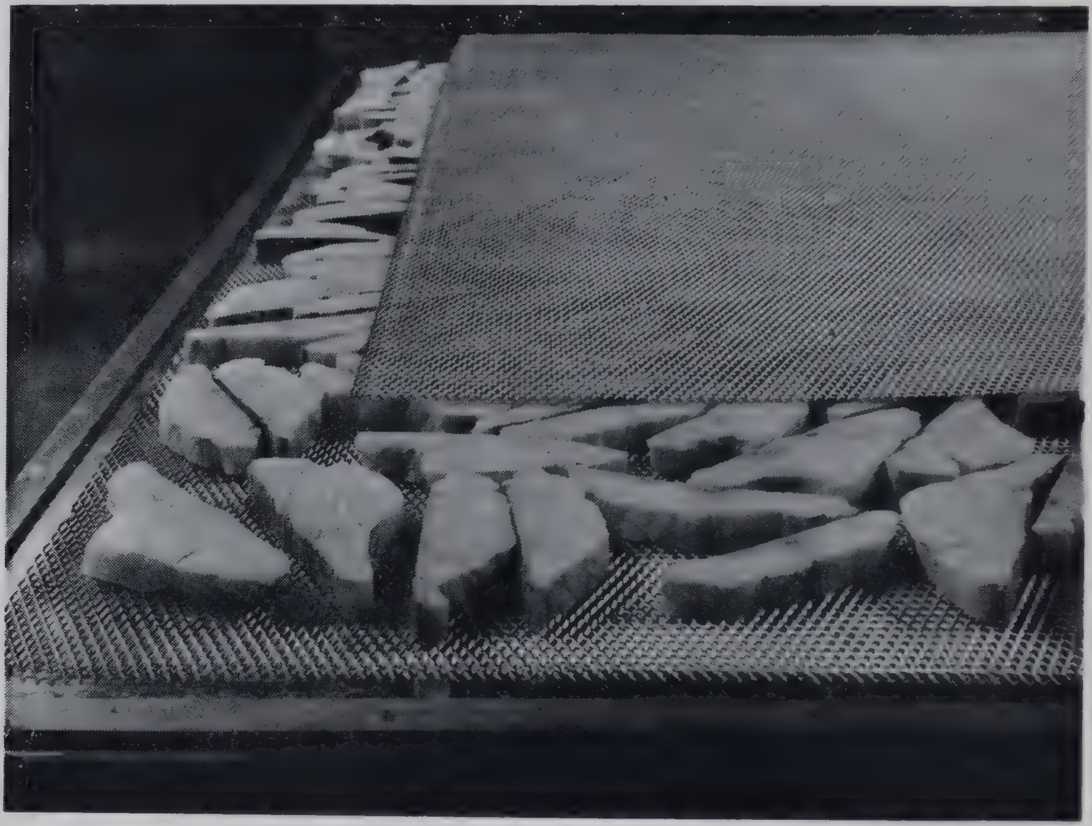


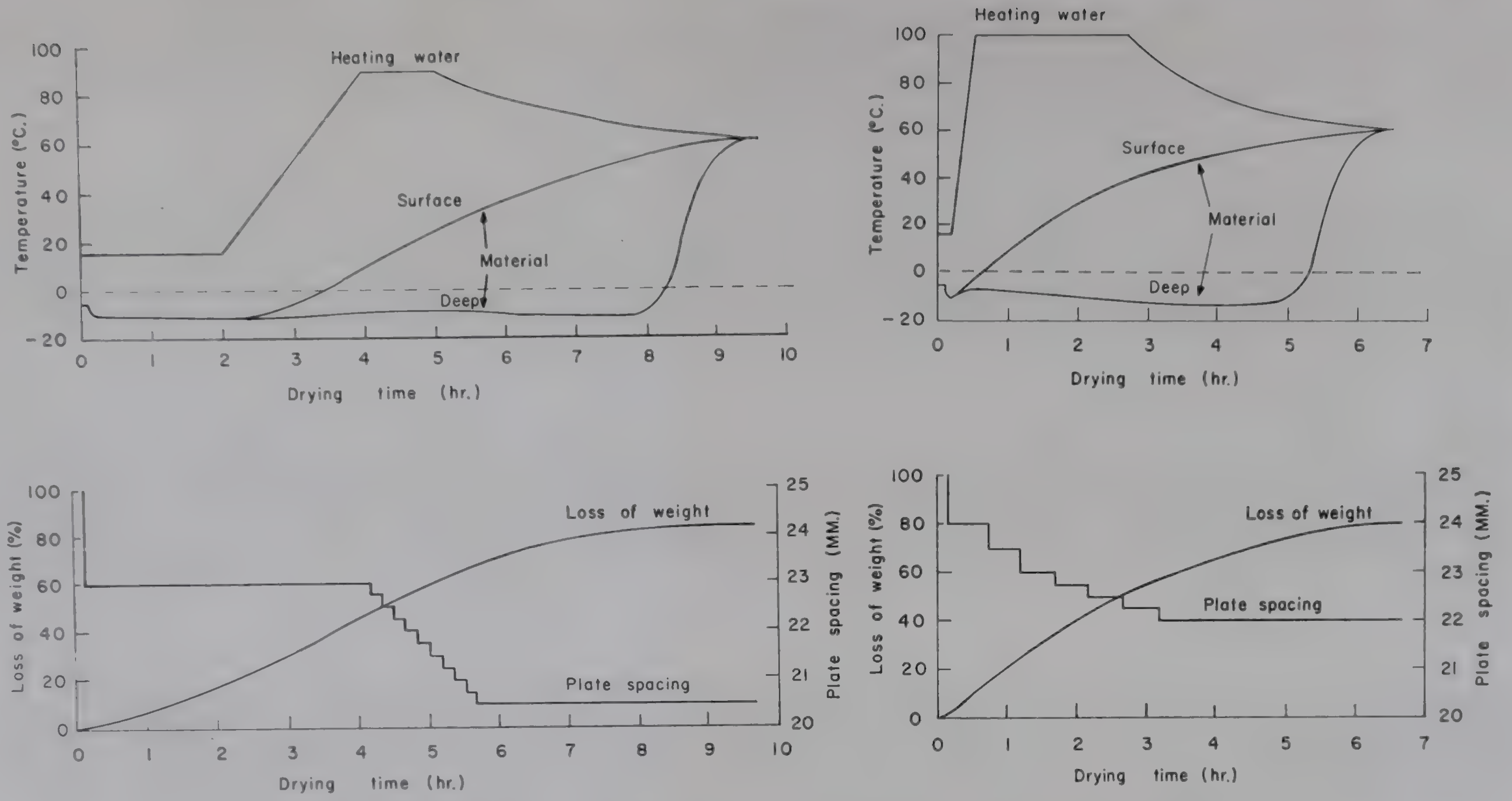
FIG. 12. Prefrozen cod cutlets loaded between expanded aluminum sheets in the "Accelerated Freeze-Drying" process.

H. HEATED SPIKE FREEZE-DRYING

It is of interest to mention that Brynko and Smithies (1958) devised a method of increasing the rate of heat transfer which resulted in drying rates considerably in excess of those of the AFD method. In their method, pieces of meat 19 mm. thick were laid between heater plates fitted with metal spikes. The spikes pierced the meat and conducted heat uniformly and efficiently into the material, and in this way freeze-drying could be completed in 3 to 5 hr. Unfortunately, the practical difficulties involved in impaling the material on the spikes, removing the spikes after drying and keeping them clean have prevented this method from being applied on an industrial scale.

I. VACUUM FAT DRYING

Platt and Heard (1946) patented a method in which foodstuffs "in a suitably sized state" are dried by heating the pieces in oil or fat under



(a) (b)

FIG. 13. Temperature behavior on surface and within cod cutlets 17 mm. thick and of water in the heating plates in large-scale vacuum freeze-drying; and corresponding weight loss and plate separation. *a*: VCD process and *b*: AFD process. Average absolute pressure, *a* and *b*: 1.3 mm. Hg; final moisture content, *a*: 2.5% and *b*: 2.3%.

reduced pressure at about 80°C. The fat can later be removed by drainage, or by centrifuging, or by means of a solvent. It is claimed that fish can be dried in this manner.

Details of the procedure necessary to dry fish are not given, however, nor are drying times. The closest approach to the drying behavior of fish is given by data for raw beef mince which was dried to a water content of 14% after 130 min. No information is given on rates of reconstitution or on the acceptability of the product when reconstituted and cooked.

The method has not been adopted commercially.

J. DEHYDRO-FREEZING

Dehydro-freezing, as its name implies, is a method of food preservation involving the partial drying of the product and subsequent storage at low temperature. The main advantage resulting is that the food is considerably debulked and is, consequently, more economically stored and transported. When required for consumption, it is thawed and reconstituted before preparation.

Although fruit and vegetables have been processed in this way (Talburt and Lindquist, 1954), it is evident from the apparent absence of industrial application that the method is not economically feasible as far as these products are concerned.

The present author has examined the possibility of dehydro-freezing fish. Two groups of cod fillet pieces $10 \times 5 \times 1.5$ cm^3. were dried in a wind tunnel at 30°C. and at 30% R.H., under which conditions the drying time-constant was 14.05 hr. The first group was dried to a weight loss of 20.1% (25.1% of the initial moisture content), and the second group was dried to a weight loss of 49.5% (61.9% of the initial moisture content). The fillets were frozen and stored at —30°C. for 132 days, thawed and reconstituted in distilled water at 20°C. The rates of reconstitution were very slow, the water uptake curves being of the form

$$W_t = W_\infty (1 - e^{-t/\tau_r})$$

W_t being the weight of water absorbed at time t after commencement of reconstitution, W_∞ the weight absorbed after immersion for an "infinite" time, and τ_r a constant—the "reconstitution time-constant."

The constant τ_r was 3.47 hr. for the first group and 12.0 hr. for the second group. The former regained 95.6%, and the latter only 76.3%, of their initial water content.

Taste panel assessment of the cooked fish showed both groups to be slightly unpleasant and "unfishlike" to the palate, to have an unfamiliar smell, and to be tough and stringy.

The results suggested that the method of dehydro-freezing is unsuitable for the preservation of fish on account of the long reconstitution time, and, more especially, of the inferior and "unfishlike" quality of the cooked, reconstituted product.

IV. Appraisal of Dehydration as a Process

A. QUALITY ASPECTS

No dehydrated fish as yet is sufficiently satisfactory to be indistinguishable from raw fresh fish. However, some products, when incorporated into certain fish dishes, are satisfactory enough. On the other hand, they are not necessarily good enough for use in such standard dishes as fried fish.

Traditionally dried fish, such as stockfish and salt fish, require a considerable time for reconstitution. Unsalted fish is first soaked for many hours in cold water before cooking (the actual time depending on the thickness). Salt fish is usually immersed in cold water overnight, after which the water is decanted and the fish is soaked for a further period of a few hours in fresh water before being cooked. It is often necessary to change the water during the process of cooking in order to reduce the saltiness to a level at which the fish is palatable. Even so, these products are aften excessively salty to most palates accustomed to fresh fish.

All traditional products, when finally ready to eat, are rubbery in texture, difficult to chew, and have a characteristic "cured" flavor. In many tropical countries, dried fish has such a pronounced flavor that it can only be used as a condiment.

The warm-air-dried product developed in the United Kingdom during World War II can be reconstituted in about 10 min. in cold water. Owing to its granular nature, it is most readily made into fish cakes, kedgerees, or pies, and it is possible to prepare more ambitious and attractive dishes, such as fish soufflé. Although acceptable to most consumers, this product is, nevertheless, very different from fresh fish.

Freeze-dried white fish such as is produced by the AFD process is readily reconstituted in cold water in 2 to 3 min. and may be cooked in much the same way as fresh fish. There can be no doubt that this product comes closest in appearance to fresh fish, but in taste and texture it still leaves something to be desired. The taste is "neutral" and not quite "fishlike" and the muscle fibers are somewhat tough to chew (Anonymous, 1957, 1958; Voskresensky, 1959). Nevertheless, when suitably flavored and garnished it is generally acceptable.

The reasons for the failure of dehydrated fish to reach perfection are not hard to find. In the first place, owing to the irreversible changes that take place during drying (denaturation) and the severe damage suffered by the cellular structure, real reconstitution is impossible. The best that can be done is to conserve a porous structure which absorbs and retains sufficient water by capillarity. Compressed products absorb slowly and less completely. With the most successful products, something like 3.5 g. per gram of dried fish can be held. However, as this water is not all "bound," some of it can easily be removed again by pressure or boiled off during cooking in fat.

The manner in which dehydrated fish is prepared for cooking is of considerable importance. Prolonged soaking is undesirable as it is inconvenient and can even be dangerous, since it presents a potential bacteriological hazard. From this point of view, air-dried minced fish and vacuum freeze-dried fish are both very satisfactory. It is evident, too, that all types of dehydrated fish benefit from skilled culinary treatment: unwanted flavors in traditional products are often better masked, while the absence of flavor in the newer products calls for garnishing.

Storage tests (Anonymous 1957, 1958) with nitrogen-packed raw and cooked freeze-dried cod fillets show that there is little or no deterioration in texture and taste over a period of many months among samples stored at 0°C. and 18°C. Samples stored at 37°C. deteriorate rapidly, becoming badly discolored, tough and objectionable to taste after only one month. The discoloration is due to nonenzymic reactions known as "browning" (Jones, 1954a, 1954b, 1957) and the toughening results from cross-links between protein molecules (Connell, 1959).

However, workers at the Experimental Factory, Aberdeen, have found that the storage-life of freeze-dried fish a 37°C. is very sensitive to moisture content. Above 5 g. water/100 g. nonfatty solids, the fish will be inedible in about a month. At or below 2 g. water/100 g. nonfatty solids, the fish will be palatable after 1 year.

The effect of reducing the moisture content by a given amount is much greater at lower moisture levels (Matheson and Penny, 1961).

B. Costs

Finally, as regards cost, the main components are: (1) raw materials, (2) labor, (3) fuel, (4) depreciation on plant, and (5) packaging. The raw material cost per pound of dried product depends on the yield of product from the whole fish and the species used. Steam, electricity, and water costs are usually small—only about a cent per pound dry—except for vacuum freeze-drying, where they amount to about 6 cents per pound. Labor and depreciation costs vary greatly with the process. Packaging costs depend largely on the amount of debulking that can be achieved, a likely range being 3 to 20 cents per pound dry. The actual cost of the drying process itself as itemized under (2), (3) and (4) above is relatively very cheap, and even the most advanced process, that of accelerated freeze-drying, amounts to only 16 cents per pound dry.

At one extreme, ordinary fish meal is being sold for as little as 3 cents per pound. At the other extreme, vacuum freeze-dried fish could probably not be sold for less than $2.00 per pound. In between, the warm-air-dried minced product might cost 80 cents per pound and salt fish about 20 cents per pound.

For a full treatment of the economics of the AFD method, readers are referred to a publication by Hanson (1961) describing all aspects of the process.

LIST OF SYMBOLS

A	Area
B	Constant in Apjohn's equation
C	Concentration of water
D	Diffusion coefficient of water
E	Activation energy per mole for diffusion
F	Fat content
H	Heat
K	Permeability constant
L	Latent heat of evaporation
M	Molecular weight
P	Atmospheric pressure
R	Gas constant
T	Absolute temperature
W	Total weight of system, water content
a	Radius
a,b,c	Axial distances
e	Base of natural logarithm
f	Flux
i	Integer
h	Enthalpy
k	Transfer coefficient, thermal conductivity
l	Length
l,m,n	Integers
m	Mass
p	Pressure
r	Radial displacement, integer
t	Time
u	Velocity
v	Specific volume
w	Water content relative to dry weight
x,y,z	Axial distances
α	Coefficient of capture, parameter as defined in Equation (17)
ε	Rate of evaporation per unit area
θ	Temperature in degrees Celsius
λ	Mean free path
μ	Viscosity
ϱ	Density
τ	Time constant

SUBSCRIPTS

a	Air, apparent
c	Critical
e	Escape, equilibrium
eff	Effective
h	Heat
i	Ice
i	First phase of falling rate period
ii	Second phase of falling rate period
m	Average
s	Surface
sat	Saturation
w	Mass, wet-bulb
x,y,z	In the direction of x,y,z respectively
0	Initial
1	Liquid phase
2	Vapor phase
∞	Infinity

OPERATORS

d	Differential
∂	Partial differential
div	Divergence
grad	Gradient
∇	Nabla or del

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CHAPTER 2

Smoking

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I. Introduction

Smoking, or smoke-curing as applied to fish, is a method of preservation effected by a combination of drying and the deposition of naturally produced chemicals resulting from the thermal breakdown of wood. In the course of time certain of the types of products developed have attained a special acceptability of their own, and the smoky flavor in particular has become an attraction in the manner of a condiment. Table I summarizes the most recent statistics (Food and Agriculture Organization of the United Nations, 1957) for smoked fish production of the major countries, which indicate that the U.S.S.R., Germany, and the United Kingdom are by far the largest producers and consumers, while in the diet of the United States and Canada it is of relatively minor importance (Anderson and Pedersen, 1951). However, many areas in which it is known that fish is smoked for home consumption, such as British West Africa (e.g., Steven, 1944), are excluded from the estimated world total production of some 250,000 tons. Smoking was formerly associated with heavy salting in producing a long-keeping commodity (e.g., "red" herring, see Table IV), and this type of product is still not without the possibilities of further development, in countries where the early state of industrial development, including communications, limits the rapid distribution of fresh fish (Nicholson, 1909; Graham, 1929; Cutting, 1949; Jarvis, 1954). Among most industrialized nations, the market for such "hard" cures began to decline when the railway networks, established in the middle of the nineteenth century, permitted for the first time the widespread distribution of fish in the fresh, iced state and of mildly cured, blander, and more perishable products which had been subjected to a less severe smoking treatment (Cutting, 1955; and see Volume II, Chapter 1 for further details of the history of this change). This evolutionary process is still continuing in the direction of ever more lightly processed products, and the trend has been accelerated in recent years by the growth of freezing in consumer packs, in which the preservation is taken care of by the low temperature.

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TABLE I
ESTIMATED PRODUCTION OF SMOKED FISH IN CERTAIN COUNTRIES

Country	Year	Total production (thousands of tons)	Principal species (thousands of tons)
U.S.S.R.	1956	67.8	Sturgeon
Germany (Fed. Rep.)	1956	38.1	85–90% Herring; eels, mackerel
United Kingdom	1956	16.7	Herring, mostly kippers
	1953	24.4	Cod and haddock
Union of South Africa	1956	22.2	18.1 Hake, 3.6 snoek
Netherlands	1956	15.9	11.0 Herring
United States of America	1953	11.9	5.4 Salmon, 2.9 fresh-water fish, 1.6 sablefish, 0.6 herring
Poland	1956	10.8	—
Philippines	1956	9.7	—
Thailand	1956	8.1	—
Canada	1956	5.8	4.5 Herring, 0.8 haddock, 0.3 cod, etc.
Norway	1956	4.0	Herring and sprats
Denmark	1956	3.6	1.8 Herring, 1.2 mackerel, 0.6 eel
Belgium	1955	2.4	2.1 Herring and sprats
Sweden	1955	1.6	1.0 Herring
Japan	1956	1.2	—
Chile	1956	0.2	—
Newfoundland	1956	0.2	Cod fillets
Ireland	1956	0.1	Herring
Argentine	1953	0.1	—
Taiwan	1953	0.1	—
Estimated grand total		252.0	

In addition to the dichotomy between "hard" and "mild" cures, there is a further division into the type of process, namely hot-smoking and cold-smoking, depending on whether the product emerges from the "kiln" cooked or raw. Britain has, with minor exceptions, remained a cold-smoking country, whereas the mainland of Europe has to a much larger extent favored hot-smoking, so that the United States has, from its mixed national origins, adopted a variety of both processes adapted to their own conditions (Stevenson, 1899; Jarvis, 1933, 1950).

Throughout Asia, Africa, and South America, where conditions, although varied, are generally more primitive and the climate severe, such combinations of smoking, drying, and cooking as "barbecuing," are regularly practiced, and although the products are acceptable because preserved, these are not usually such as would commend themselves to sophisticated palates of more highly developed countries (Deraniyagala, 1933; Martin, 1934; Agricultural Adviser to the Government of India, 1941; Avery, 1950).

However, the methods of smoking in general use, even in Britain, are still little removed from those of medieval times, nor even in any essential respect, excepting scale, from those used by primitive tribes, although the products, of course, present considerable differences. As far as Britain is concerned, only relatively recently has the mechanization of the process been considered, although perhaps associated with this it is already possible to detect the beginnings of an outlook more in keeping with the requirements of a food industry as regards quality control and hygiene. This change of attitude may perhaps be not unrelated to the marked decline in the consumption of smoked products in the post-1945 period, for which various reasons can be adduced, such as more plentiful supply of other foodstuffs, but it is becoming increasingly realized that a radical change in production methods and ideas is called for if smoked fish is to compete and survive.

Nor are other countries, generally speaking, greatly in advance of Britain. Possibly the smoking of fish is a declining, if not actually a dying, industry. It may be that the taste for smoke on foods is disappearing except for a minority which continues to acquire liking for this sort of flavor. Nevertheless, a considerable amount of research and development effort is being devoted in Britain (Cutting, 1942; Shewan, 1954; Food Investigation Board, 1957) and elsewhere (e.g., Le Gall, 1938; Dieuzeide and Mercier, 1941; Linton and French, 1945; Tilgner, 1957) to obtaining the scientific and technical information that would enable quality to be controlled at an attractive level.

The results of scientific interest that have so far emerged from an attack on the problems of fish smoking, under the auspices of the United Kingdom Government Department of Scientific and Industrial Research, will first be discussed in Section II before considering more practical aspects in Section III.

II. Theoretical Aspects

A. THE PHYSICS OF WOOD SMOKE

By W. W. Foster, Torry Research Station, Aberdeen, Scotland

1. *Physical Properties of Smoke*

Although very little has been published about the physical properties of wood smoke, a recent study has made it possible for a picture to be built up (Foster, 1957).

When wood is heated and undergoes destructive distillation, it gives off gases and vapors, some of which condense on nuclei in the cool zone above the fire to form a stable aerosol, composed of minute tarry droplets ("particles"), which constitutes the visible smoke. Under a given set of conditions, the mass concentration of the particle phase bears a fixed ratio to that of the vapors. The chemical composition of both phases is similar, but the particles contain a greater proportion of components of high molecular weight (see Section II, B). The partition of mass concentration between particles and vapors, as well as their chemical composition, depends on the nature of the sawdust and the conditions of combustion. The quantity of smoke deposited is a complex function of the composition and concentration of the smoke, the environmental conditions and the nature of the surface.

a. PARTICLE SIZE

The average size and size distribution of any aerosol is dependent on the conditions under which the vapors are produced and cooled (Whytlaw-Gray and Patterson, 1932). When the gases and vapors resulting from the destructive distillation of wood are diluted rapidly by air passing over the sawdust bed, as in the Torry mechanical kiln (Cutting, 1950), the consequent rapid cooling gives rise to very small particles of about 0.1 μ radius. Although the smoke cloud as a whole might be stationary, the individual particles have considerable Brownian motion, as a result of which they come into contact with each other and coagulate. The average particle radius, therefore, tends to increase. Using a theoretical equation of coagulation (Smoluchowski, 1917), calculations can be made (Table II) of the approximate time in which the number of wood smoke particles decreases to one-half the initial number, assuming negligible losses to the walls of the containing vessel. In the most simple case, each pair of particles becomes one particle of radius 3/2 times the initial radius.

The theoretical rate of coagulation of wood smoke, whose particles are about 0.1 μ radius, is rapid for mass concentrations greater than about 0.1 mg./liter. Wood smokes are usually more concentrated than this. The actual rate of coagulation of wood smoke appears to be greater than the theoretical rate (Foster, 1957). Other factors, such as turbulence and gravitational settling, can also give rise to coagulation (Langstroth and Gillespie, 1947). Since wood smoke aerosols are transient in this way, particle size analysis by sampling and microscopic examination is prone to error. Foster (1957) found that sampling by impaction and gravitational settling led to spuriously high values of average radius and that electrical deposition yielded a truer figure. After sampling, the particles were shadow cast with aluminum under vacuum. This technique was used since wood smoke particles lose at most only about 20% of their weight by evaporation. The particles were then examined under oil immersion. It was clear that the particles were spherical before deposition and were composed of very viscous liquid. However, as the particles were near to the limit of resolution of the light microscope, the average size could not be measured accurately and two indirect methods had to be used, one of which was developed during the course of the work. The optical density of the smoke from a miniature "fluidizer" (Nicol, 1957) measured by means of a meter (Section II, A, 4, b), was controlled by means of the mechanism which fed sawdust to the "fluidizer." This smoke was then passed through a short, earthed cylinder containing a fine axial corona wire at a high voltage. Although some of the particles were precipitated in this charger, most of the smoke passed through the tube. As is the case for other smokes produced by low-temperature distillation, a small proportion of the particles of normal wood smoke are charged, but the number of charges on each particle is never more

TABLE II

TIME IN SECONDS IN WHICH NUMBER OF PARTICLES DECREASES TO HALF THE INITIAL NUMBER

Mass concentration (mg./liter)	Initial radius (μ)			
	0.05	0.10	0.15	0.20
0.01	125	1,000	3,375	8,000
0.05	25	200	675	1,600
0.10	12.5	100	338	800
0.20	6.3	50	169	400
0.30	4.2	33	113	267
0.40	3.1	25	85	200
0.50	2.5	20	68	160
1.00	1.3	10	34	80

than a few electron units. Furthermore, there appear to be equal proportions of positive and negative charges and the smoke as a whole is, therefore, electrically neutral. When the corona charging field was intense enough (e.g., a voltage greater than 6 kv. on a 36 swg. wire in a tube of diameter 2.5 cm.), the particles emerging from the charger were electrically charged with the same sign as the corona wire. The charged smoke was then passed through a long tube consisting of short cylindrical sections which could be weighed. No external field was applied to the charged smoke inside the tube but it deposited copiously on the inside walls of the tube as a result of mutual repulsion of the charged particles. Residual smoke leaving the long tube was collected by a final electrical precipitator. By determining the distribution of weight of the smoke deposited in the tube and by measuring the total charge given up by the particles, the average particle radius was calculated to be about 0.10 μ, which agreed fairly well with that which was calculated from measurements of the optical density and the mass concentration of the particle phase (about 0.14 μ), and with the direct observation that wood smoke particles were near to the limit of visual resolution.

b. Rate of Deposition

Uncharged aerosol particles deposit on surfaces under the influence of forces of gravity, turbulence, diffusion (Brownian motion), and a force arising from the effects of any temperature gradient, known as the radiometer force (Epstein, 1929; Rosenblatt and LaMer, 1946; Saxton and Ranz, 1952). Fresh smoke (of the order 0.1 μ radius) deposits mainly under the influence of diffusion and radiometer forces and old smoke (which can be of the order 0.5 μ radius) deposits mainly under the influence of gravitational and turbulence forces. However, the rate of deposition of wood smoke particles on dry metal surfaces is only of the order micrograms/cm.^{2}/hour.

2. *Electrostatic Deposition*

To enhance the rate of deposition of the particle phase of wood smoke, electrical methods of precipitation may be used. In the most common method as applied to food processing, the smoke particles are charged and deposited in the electrical field which is applied between fine wires at a high voltage and the earthed flesh (Hamm and Rust, 1947; Hanley *et al.*, 1955; Sikorski, 1956; Anonymous, 1954). The main disadvantages of this method are that the high voltage electrodes must be near to the flesh, so giving rise to safety and arcing problems, and that existing plants cannot be easily adapted to electrostatic smoking. Furthermore, it is not possible to treat large quantities of fish simultaneously.

To overcome some of these disadvantages, the particles were charged and then allowed to disperse among fish mainly under the action of forces of mutual repulsion (Foster and Jason, 1954; Foster, 1956). In this way, large quantities of fish could be processed batch-wise. The possibility of danger to personnel was reduced; arcing could not occur between the high voltage electrodes and the fish, and existing kilns could be converted for a small capital cost. A Torry kiln was converted to the new process by placing at the inlet plenum of the kiln a charging unit which consisted of alternate wires (36 swg.) at a high voltage (about 10 kv.) and 2.5 cm.-diameter earthed rods, the rods being about 6.3 cm. center to center. For lightness, tubes of the same outside diameter (2.5 cm.) could be substituted for the rods. After passing through the charging unit, the charged smoke dispersed among the fish in the kiln. With this arrangement it was found that kippers could be smoked in about half the normal time, but that it was necessary to dry to the normal weight loss of about 15% to obtain a flavor almost indistinguishable from that of an ordinary kipper.

3. *Relative Importance of Particles and Vapors*

In view of the fact that the rate of deposition of smoke on dry surfaces was considerably enhanced by the electrical charging of the smoke, it was difficult to see why the kippering time was only cut to one-half of the normal value. Further experiments showed that the process of deposition of smoke on wet surfaces (such as water, white fish, and herrings) is completely different from that on dry surfaces. In the former case, the vapors contribute much more to the total deposit than the particles. In studying the relative contributions of the particle and vapor phases, some water surfaces were smoked with the vapors and the particles together and others were smoked with the vapors alone, after clearing the smoke of particles by means of electrical precipitation. Each sample of smoked water was then freeze-dried and the weighed residue taken as an index of the total amount of smoke deposited initially on the water. The residues were dark brown, viscous, and relatively involatile, thus resembling the particle phase. It was found that the rates of deposition of smoke on water were between about five and twenty times greater than the rates of deposition of smoke on dry surfaces. The rate of deposition of smoke increased as the rate of evaporation of water during smoking increased. Furthermore, this relationship was the same whether the particles were present or not. It was concluded that the particle phase of wood smoke played an insignificant role in the process. These experiments were repeated in less detail using pieces of cod, when visual examination showed that the rate of deposition of smoke again increased as the rate of drying of the fish increased.

The deposition of smoke on fish, therefore, appears to be a process similar to that occurring in gas-scrubbing columns.

4. *Optical Properties*

a. GENERAL

In spite of the fact that the visible smoke particles are not deposited significantly on fish during smoking, experiments have shown that for any particular type of smoke, the quantity deposited on fish is, in fact, related to the "optical density," D, defined by the ratio:

$$D = \log_{10} \frac{I_0}{I_l} \qquad (1)$$

where I_0 is the initial intensity of a beam of light and I_l the intensity after it has passed through smoke for a path length l. (Thus, a smoke density of 1.0 corresponds to 90% absorption and 10% transmission of light.)

The Beer-Lambert Law:

$$I_l = I_0 \times 10^{-klc} \qquad (2)$$

where c is the mass concentration of the smoke and k is a constant (the "extinction coefficient") dependent on the nature and size distribution of the smoke particles, and the spectral distribution of the light used, has been found by Foster (1957) to apply to wood smoke.

However, the relative mass concentrations of the particle and vapor phases vary with the method of generation, so that smoke in, say, traditional kilns, mechanical kilns, and "fluidizers," having the same optical density may not be deposited at the same rate on wet surfaces. Furthermore, the optical density of the particle phase is very markedly dependent on particle size (Mie, 1908; Barnes and LaMer, 1946).

The color of the smoke depends on the particle size. The theory of the scattering of light is rather complex. Thus, at 0.1 μ diameter particle size, the smoke is red by transmitted light, while at 0.5 μ the absorption is the same for the same mass concentration, but the smoke appears blue. In both cases it is blue as a result of scattering when viewed at right angles to the direction of the incident light.

b. THE MEASUREMENT OF SMOKE

By A. C. Jason, Torry Research Station, Aberdeen, Scotland

No single characteristic of smoke or its effects is independent of the type of sawdust and conditions of production and deposition. Consequently, no absolute measure of intensity of smoking can be devised. Nevertheless, a rough index is desirable and the optical properties have been the basis of many attempts (see reviews by Locklin and Parmelee, 1950; Tasker, 1951), particularly the scattering (Anonymous, 1932) or the attenuation of light by smoke particles. The scattering method is suitable only for the measurement of smokes of very low density owing to the effects of multiple scattering which becomes serious when the particles are very close. Methods based on the attenuation of light do not suffer so severely from this disadvantage, and, in general, they are simpler.

Subjective methods have been used, such as the visibility of a number of equally spaced objects placed in the smoke in line with the observer, the number of objects just visible being a measure of the density of the smoke; or the distance at which an object, a letter, a number, or a self-luminous source can just be distinguished.

Ringelmann (see Donkin, 1898) devised a series of numbered charts on each of which was inscribed a black rectangular grille on a white background; the thicknesses of the lines of the grille were varied from chart to chart so that when viewed at a distance they appeared as graduated shades of grey, varying from white to black in five steps. The number of the chart which most closely matched the smoke was called the "Ringelmann number." The accuracy of the method (which is still in use), and of all such methods, suffers from the effects of the intensity, direction, and type of lighting, the extension of the smoke, the distance of the observer, and his judgment.

When photoelectric cells became available, various objective methods of measuring the optical density of smoke were devised. The simplest of these is the measurement of the attenuation of light passing through the smoke by means of a barrier layer photoelectric cell. The arrangement consists simply of a lamp and lens which project a parallel beam of light through the smoke onto the cell, the output from which is measured by a meter. The current through the meter, therefore, becomes a measure of the light attenuated by the smoke.

It is evident from Eq. 1 that the attenuation of the light $(I_0 - I)/I_0$ sometimes expressed as "percentage obscuration" (i.e., $100\,(I_0 - I)/I_0$), is not proportional to the optical density of the smoke and is, therefore, not a satisfactory index of this quantity. In general, commercially available smokemeters indicate "smoke density" either as "percentage obscuration" or as a "Ringelmann number" or as an arbitrary number, and there is often no direct way of relating the measurements of one indication to those of another.

Combining Eqs. 1 and 2 we have

$$D = klc \tag{3}$$

Hence:

$$\frac{D}{l} = kc = S \tag{4}$$

Thus for a given smoke and a given light source the quantity S, the optical density per unit length, may therefore be used to define the density of the smoke since it gives a direct method of estimating the actual mass of smoke particles present in a given volume.

A barrier-layer photoelectric cell provides an output current proportional to the intensity of the light falling on its surface provided that the external load is less than a few hundred ohms. This is the basis of operation of most industrial smokemeters. The "percentage obscuration" is derived simply from a suitably graduated meter scale on which "zero obscuration" corresponds to the position of the pointer when no smoke is present and "100% obscuration" to its position when no light is transmitted. Although linear in "percentage obscuration," this method of presentation becomes increasingly insensitive as smoke density increases. Additional, more serious, disadvantages inherent in this simple form of smokemeter are: (a) aging of lamp; (b) sagging of lamp filament; (c) fluctuation of lamp intensity with mains supply variations; (d) short- and long-term fatigue of photoelectric cell; (e) temperature sensitivity of photoelectric cell characteristics; (f) deposition of smoke on end windows defining light path in smoke.

Errors arising from variations in the characteristics of the detector, but not of the source may be considerably reduced by the double-beam method first proposed by Darwin (1906). Numerous photoelectric densitometers have been designed to reduce or to eliminate one or more of these sources of error but mostly for the measurement of the densities of photographic images.

More recently a recording smokemeter has been devised, in connection with research on domestic solid fuel appliances (Littlewood, 1956) in which the effects of mains supply variations, temperature sensitivity, and smoke deposition on end windows have been considerably reduced. This instrument is notable for the introduction of a neutral density optical wedge in a double-beam null-balancing system using two lamp and photoelectric cell units, one in the flue and the other in the recorder itself. The optical wedge is made to vary the output from the photoelectric cell in the recorder to correspond with that in the flue unit and its position then serves to indicate the optical density of the smoke. Difficulties arising from the differential aging of the lamps and photoelectric cells are, however, still present.

The problem has been completely resolved in its application to the measurement of smoke in chimneys by a double-beam method null-balancing system (Bredl and Marsdon, 1950).

Several difficulties peculiar to the application of these instruments to the measurement of smoke in fish kilns arise from the nature and function of these kilns. In general the dimensions of a kiln are such that a beam of light traversing its width is too severely attenuated for convenient measurements of its intensity. Often a number of kilns are grouped together side-by-side in smokehouses where it is not possible to mount a source and detector externally with respect to each smokehouse. Smoking times of several hours are common and kilns are frequently not completely cleared of smoke for several days so that zero adjustment of an instrument is, therefore, not convenient. Furthermore, the precautions normally taken to prevent smoke deposition on the surfaces of the end windows of industrial smokemeters (such as allowing clean air from outside the chimney to be drawn by convection over the windows) are not practicable under the conditions obtaining. A smokemeter for use in such kilns must be reliable, stable, robust, and inexpensive.

Two instruments have been designed at the Torry Research Station, one sacrificing some stability for cheapness and the other gaining stability at the expense of simplicity.

The simpler of these (Storey, 1957) consists essentially of a stabilized source of parallel light (Fig. 1) which passes through a fixed length of smoke onto a detector. The whole arrangement is supported on a short frame which is suspended entirely within the kiln. Sufficiently good stabilization of the source is provided by energizing a slightly underrun lamp with a constant voltage transformer fed from the mains supply. The detector consists of a barrier-layer photoelectric cell which is coupled to a meter in series with a variable resistance. When the total external resistance in the cell circuit is sufficiently high the output current i is approximately represented by the relationship

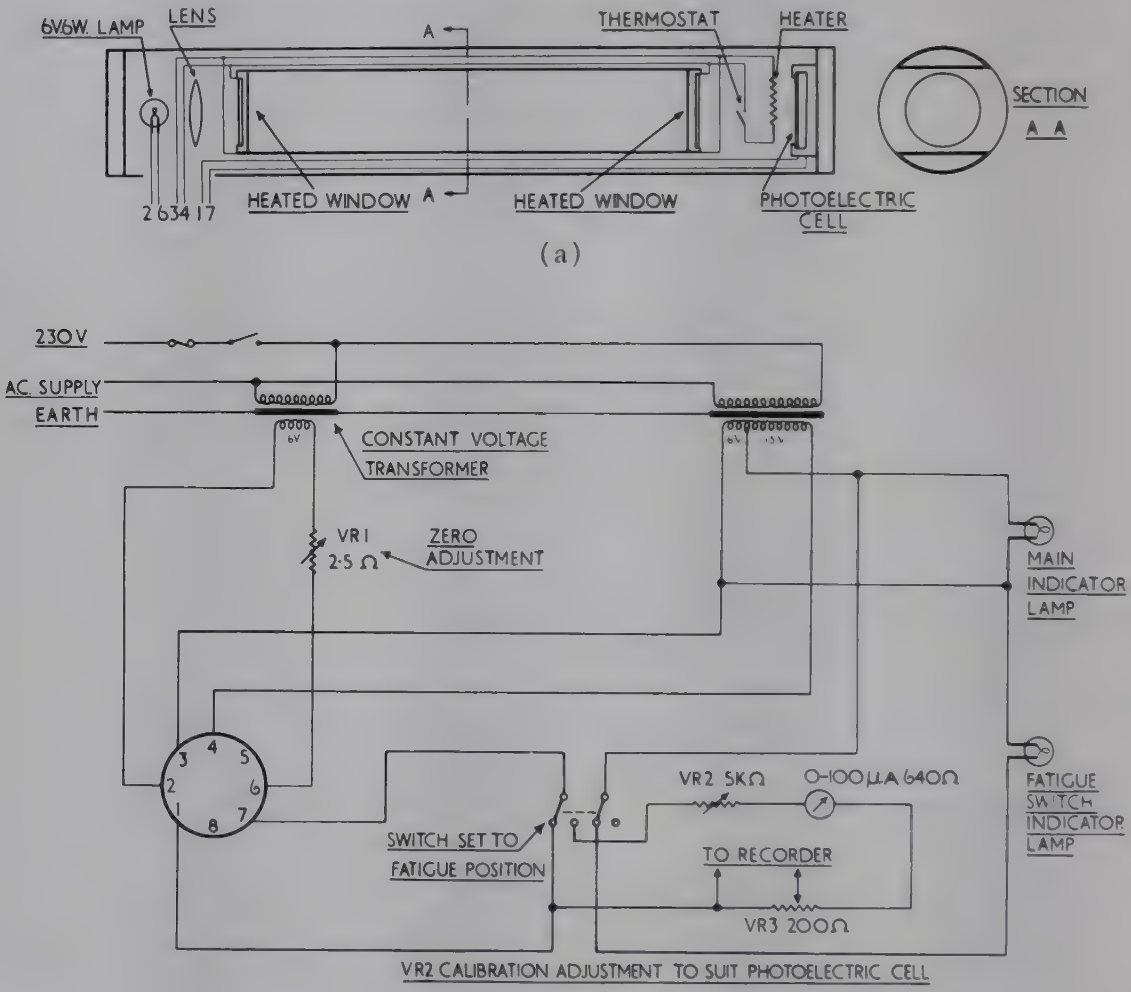
$$i = \text{constant} \times \log_{10} I \tag{5}$$

Thus, combining Eqs. (1), (4), and (5)

$$S = \frac{1}{l} C (i_0 - i) \tag{6}$$

where C is a constant and i_0 is the cell current corresponding to zero smoke density. The meter may, therefore, be engraved with a scale linear in smoke density.

The instrument is calibrated initially and checked subsequently by means of neutral density filters inserted in the light beam, the required output of the photoelectric cell to give the desired meter reading being obtained by alternately adjusting the brightness of the lamp by means of the variable resistance VR1 and the resistance VR2 in series with the meter. Calibration normally extends over the range 0–0.5 optical density per foot, sufficient to measure the densities of most smokes encountered in fish-curing kilns.


6V6W. LAMP
LENS
A
THERMOSTAT
HEATER
SECTION A A
2 6 3 4 1 7
HEATED WINDOW
A
HEATED WINDOW
PHOTOELECTRIC CELL
230 V
A.C. SUPPLY
EARTH
6V
CONSTANT VOLTAGE TRANSFORMER
VR1 2·5 Ω
ZERO ADJUSTMENT
MAIN INDICATOR LAMP
1 2 3 4 5 6 7 8
VR2 5KΩ
0–100 μA 640Ω
SWITCH SET TO FATIGUE POSITION
TO RECORDER
VR3 200Ω
FATIGUE SWITCH INDICATOR LAMP
VR2 CALIBRATION ADJUSTMENT TO SUIT PHOTOELECTRIC CELL

(a)

(b)

FIG. 1. Simple smokemeter. (a) Detector unit; (b) indicator unit circuit diagram.

In this instrument short-term fatigue of the photoelectric cell is effectively overcome by short-circuiting it for 5 to 10 min. while it is fully illuminated, by means of the switch shown in Fig. 1. Subsequent short-circuiting is normally not necessary, except to check the calibration or after the lamp has been extinguished. The effect of temperature drift on the cell characteristics is obviated by thermostatically controlling the temperature of the photocell compartment.

Obscuration of the ports defining the light path due to the deposition of smoke is prevented by heating the windows with an electric current passing through a transparent conducting layer of stannous oxide deposited on their surfaces.

The second instrument is a recording smokemeter (Jason, 1956) based on a variant of the double beam method. The schematic arrangement is shown in Fig. 2.

In this arrangement light which passes through the smoke is also absorbed by a narrow portion of an annular optical wedge which moves in front of an aperture. As the smoke density varies, the position of the optical wedge is continuously adjusted automatically in such a manner as to maintain constant attenuation of light along the beam. This is achieved by comparing the intensity of the transmitted light with that which passes through a sealed-off reference column, using a split barrier-layer photoelectric cell. The potential difference between the two sections of the cell connected in opposition is fed into an amplifier controlling the speed and direction of rotation of a servo-motor. The servo-motor rotates the annular optical wedge in such a direction as to reduce the potential difference to zero and thus to maintain constant attenuation of light in the smoke path. The servo-motor is also coupled to a pen-arm which carries a stylus across a moving chart and thus provides a record of the smoke density. Since the optical density at any point along the annulus of the optical wedge is a linear function of the angular displacement of the radial line through the point, and the movement of the pen-arm is constructed to be proportional to the rotation

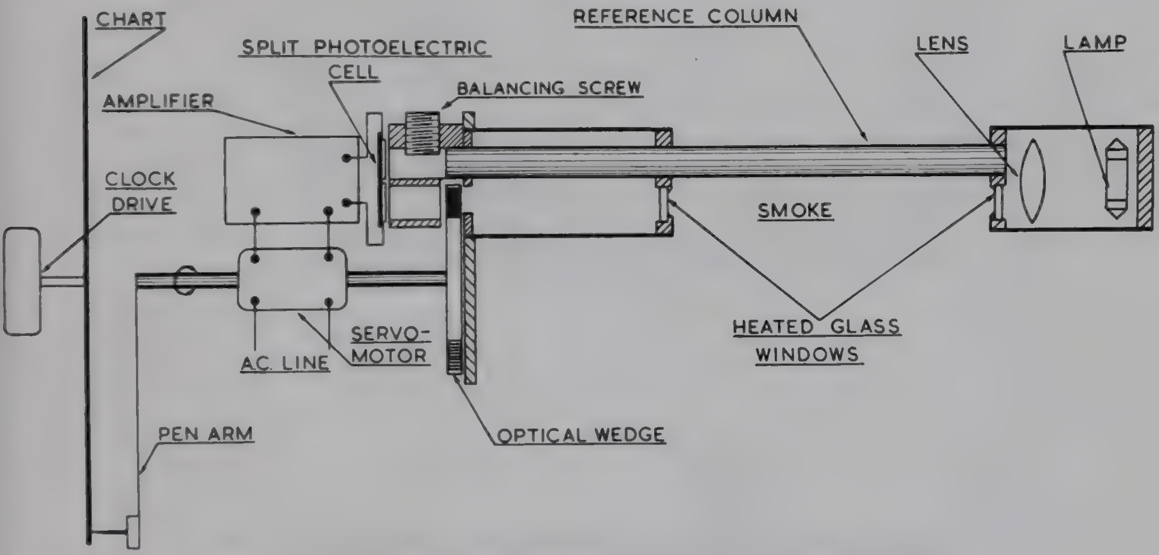
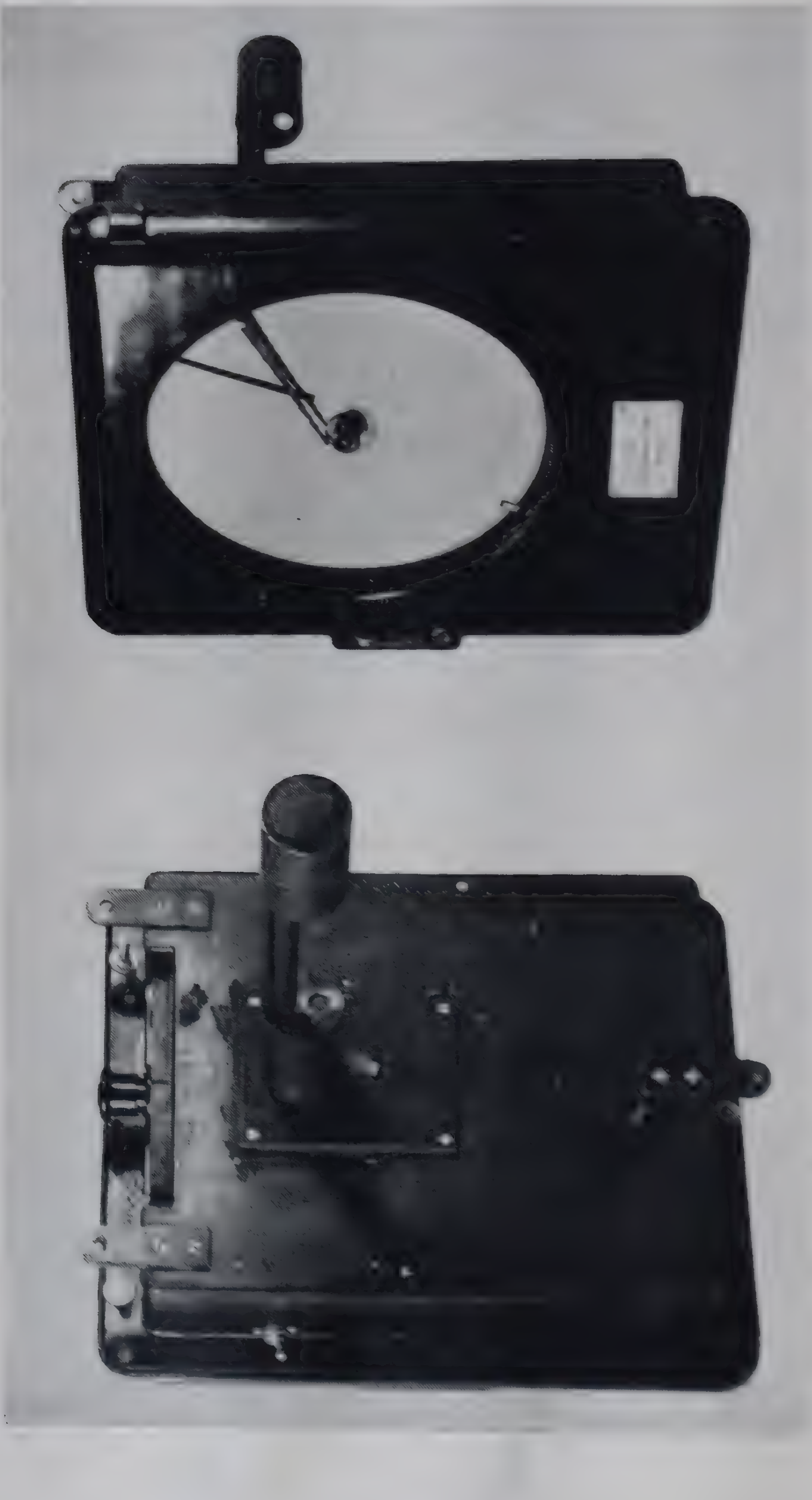


FIG. 2. Schematic arrangement of recording smokemeter.



Front

Rear

FIG. 3. Front and rear views of recording smokemeter.

of the optical wedge, the indication may be made to coincide with a printed scale on the chart.

Again the compartment containing the photoelectric cell is thermostatically controlled and the end windows are electrically heated.

Figure 3 shows general views of the front and rear of the instrument, the measuring head being inserted through a hole in the side of the kiln.

B. THE CHEMISTRY OF WOOD SMOKE

By T. H. Simpson, Torry Research Station, Aberdeen, Scotland

The combination of combustion and destructive distillation which occurs when smoke is produced from smoldering wood results in a complex mixture of aliphatic and aromatic compounds in addition to water and carbon dioxide (the end products of complete combustion), and traces of hydrogen and carbon monoxide. The relative quantities of individual constituents of wood smoke are highly variable and are determined by the contributions made by individual chemical reactions to the over-all process; these reactions are, in turn, controlled by the conditions of smoke production.

Pettet and Lane (1940) effected a separation of smoke into various chemical groups, viz., aldehydes, ketones, acids, phenols, hydrocarbons, and tars, and showed that the composition was dependent on the air speed over the fire.

TABLE III

ALIPHATIC COMPOUNDS PRODUCED BY THE POLYOSES OF WOOD

Methanol Ethanol Propanol	Formaldehyde Acetaldehyde Propionaldehyde Acrylaldehyde Furfuraldehyde 5-Methylfurfuraldehyde	Acetone Diacetal	Formic acid Acetic acid Propionic acid

Recently, at Torry Reseach Station, Simpson (1958) has been studying the chemistry of wood smoke and smoked fish, paying particular attention to the deposition of phenolic constituents. The evidence so far collected can be summarized as follows.

Wood consists of two main fractions, viz., *polyoses* (including pentosans) which take the part of the "flesh" of the tree, and *lignins,* which supply the structure. "Soft woods," e.g., conifers, frequently contain, in addition, *resin,* which is essentially turpentine, a mixture of terpenes, with dissolved rosin, a mixture of hydrophenanthrene derivatives.

Under the conditions of smoke production, the polyose fraction undergoes degradation and yields the compounds listed in Table III. Bugge (1927) lists 69 aliphatic compounds isolated from the products of distillation of nonresinous wood at room temperature, which probably also derive from the polyose portions of wood. Many of these compounds are almost certainly to be found in wood smoke.

The structures of the lignins which comprise about one-third of the solid matter of wood have not yet been fully elucidated (Brauns, 1952; Smith, 1956). It is, however, generally agreed that they may be represented (see Fig. 4) as being formed from two main building stones, a guaiacyl propane (I) and a syringyl propane (II); a third building stone, a *p*-hydroxyphenyl propane has been recognized in the lignins of grasses. The states of oxidation of the propane side chains and the natures of the linkages between one building stone and the next have yet to be established, though it seems likely that at least some of the side chains are condensed with the next units at position 6.

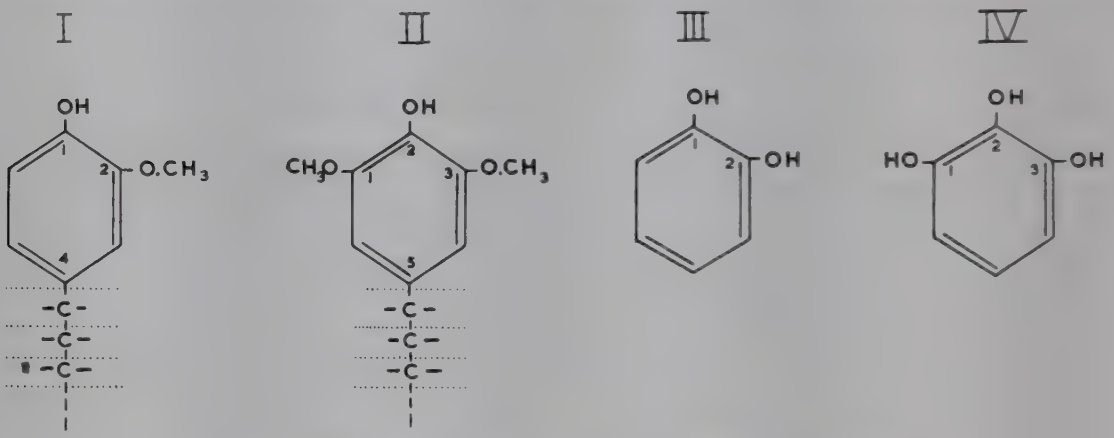


FIG. 4. Production of phenols by degradation of lignin.

Under the conditions of smoke production, the lignins of wood are, in part at least, broken down, giving a complex mixture of phenols. Each individual phenolic compound may, however, be considered as being formed from the building stones by relatively simple reactions, viz., reduction, partial or complete side chain elimination, hydrolytic cleavage, or combinations of these. Thus, among the phenolic constituents of wood smoke the following have been detected: guaiacol, its 4-methyl ethyl and propyl homologs and its 6-alkyl homologs, catechol (III) and its 4-methyl derivative, pyrogallol (IV), its 1-*o*-methyl and its 1,3-*o*-*o*-dimethyl ethers and their homologs, hydroquinone (possibly formed by hydrolytic fission of the side chain) phenol and *p*-cresol. The major phenolic constituents are the guaiacol, 1,3-dimethylpyrogallol and catechol groups. These groups are present, though in greatly different relative concentrations in both the particle and in the vapor phases of wood smoke, the vapor being, as expected, much richer in volatile phenols, e.g., guaiacol and its homologs, and poorer in less volatile compounds, e.g., pyrogallol, hydroquinone, and catechol, than the particle phase. Foster and Simpson (1958) have used these observations to demonstrate the importance of the vapor phase in the smoking process, fish "smoked" in total smoke and in vapors alone showing identical phenol distribution patterns. Since small contributions from the particle phase were readily detectable, their conclusion that vapors are pre-eminently important to the smoking process seems to be inescapable.

The British Empire Cancer Campaign (1941) reported that polycyclic aromatic compounds could not be detected in wood smoke and that there was no evidence of wood smoke having carcinogenic activity. It is now commonly believed that the pyrolysis of many organic natural products gives rise to traces of 3,4-benzpyrene and related compounds and it seemed likely that the use of the refined chromatographic techniques now available would establish the presence of microscopic traces of these compounds in wood smoke (Tilgner and Müller, 1957). However, it seems likely that these compounds, if present, would tend to be concentrated in the particle phase and would not, therefore, be absorbed by the fish (see, however, Dobeš *et al.*, 1954).

The various roles which individual constituents play in the preservation and flavoring of smoked fish have not yet been fully elucidated. Shewan (1945) has suggested that the color formation of smoked fish is related to the deposition and subsequent oxidation of phenols, the oxidation being, as is well known, accelerated under alkaline conditions. Dauphinée (1925) has in fact suggested the addition of sodium bicarbonate to brines, and Taylor (1930) has suggested the addition of ammonia to the smoke itself as a means of intensifying the natural coloration of smoked fish. Later workers (Linton and French, 1945) have concluded that, while the intensity of color is roughly proportional to the quantities of phenols deposited on the fish, phenols are not themselves directly involved in color formation.

Wood smoke is known to be an effective antioxidant, providing useful protection against autoxidation to fatty fish and fish meal (Banks, 1952) and fish oils (Nikkilä and Linko, 1951). In a recent investigation Banks and Simpson (1958) separated smoke by countercurrent distribution and examined the fractions for activity in the model system, hematin catalyzed autoxidation of methyl linoleate in aqueous emulsions. In normal smoking, guaiacol and its homologs and to a lesser extent 1,3-*o*-*o*-dimethylpyrogallol, absorbed from the vapor phase, were found to account for the greater part of the antioxidant activity. "Electrostatic" smoking imparted to fish a greater degree of protection than does normal smoking, the increase being found to be due to the additional deposition of the highly active antioxidants catechol, 4-methylcatechol and pyrogallol 1-*o*-methyl ether from the particle phase.

Formaldehyde, acids, and phenols are familiar preservatives and have long been regarded as being responsible for the biological stability of smoked fish. Opinion about the nature of the effective bactericides has, however, been divided, Hess (1929) believing formaldehyde and Metzner (1933) and Griffiths and Lemon (1934) considering the tar constituents to be the active agents. Shewan (1949) has tabulated material from various sources (principally McCulloch, 1936; Rao *et al.*, 1932) which shows that wood tar phenols are the most active inhibitors of *Eberthella typhi* and *Staphylococcus aureus,* and Simpson (1958) has shown that the inhibition of a typical marine achromobacter is due principally to guaiacol and pyrogallol ethers and their homologs. However, since fish has a bacterial population, initial and introduced in handling, that is variable and since the compounds which kill the greater part of the original flora may well be different from those which restrict the growth of smoke-resistant organisms it seems reasonable that the antiseptic compounds of smoke should only be defined in terms of the bacterial population and the nature of the smoked product.

Under present commercial conditions, adequacy of smoking is usually gauged by the color of the smoked fish, though this criterion is rendered less sensitive by the widespread use of dyes. Various analytical procedures have been tried in an attempt to find some reliable objective index of the extent of smoke deposition. Formaldehyde has been estimated in smoked fish by Griffiths and Lemon (1934), by Callow (1927), Linton and French (1945), and Shewan (1945). Since the last author has shown that unsmoked fish can give relatively high "blank" values, depending on its staleness, formaldehyde content cannot be regarded as providing a reliable criterion of smoking. Volatile acids have been estimated by Linton and French (1945) but once again, high and irreproducible blank values are given by unsmoked fish. Acetone determinations have also been made by Linton and French, but they consider them to be less reliable than phenol estimations. "Phenols" in smoked fish have been determined by Shewan (1945), Linton and French (1945) and Simpson (1958), aqueous extracts, steam distillates, or ethereal extracts being estimated colorimetrically with Gibbs's (1927) or Folin and Ciocalteu's (1927) reagents or with 4-aminoantipyrene (Gottlieb and Marsh, 1946). The results are usually expressed in terms of quantity per 100 g. of fish (calculated as phenol) or better, in terms of quantity (or optical density of color as measured by absorptiometer) per unit area of fish surface. Although these methods are accurate and sensitive, caution is necessary in using them as criteria of smoking. They provide information about the deposition of a relatively small proportion of the total composition of wood smoke and should only be used as a smoke index when it is known that the conditions of smoke production (and possibly the physical characteristics of the kiln) are the same. One example of the need for care in interpreting the results of phenol determinations is provided by the observation that fish smoked in a traditional chimney kiln show approximately twice the phenol value for a given degree of smoky flavor (as assessed by a taste panel) as fish smoked in a mechanical kiln. When smoking conditions are the same, phenol determinations are useful; thus, Simpson and Storey (1958) have used them to show that the rate of deposition of smoke is roughly proportional to the optical density of the smoke, that the rate of deposition increases with increasing humidity and that predried fish absorbs smoke more slowly than wet fish. The use of two procedures, steam distillation and ether extraction, and two reagents, Folin and Ciocalteu's and 4-aminoantipyrene, and the measurement of phenol residues after steam distillation, provides determinations in different regions of the phenol distribution pattern and is useful in comparing different smoking procedures. It is, however, too time-consuming for routine purposes.

Phenol estimations by Shewan (1949) and Linton and French (1945) suggest that smoke constituents are concentrated in the surface pellicle, the phenol values falling from 60 mg. per 100 g. to as little as 2 mg. per 100 g. at the center of the fish. However, Jason (1958a) has shown by examination of the ultraviolet fluorescence, and Burgess (1958) by histochemical means, that diffusion from the surface to the flesh continues for several days after smoking.

C. Factors Affecting the Drying of Fish during Smoking

By A. C. Jason, Torry Research Station, Aberdeen, Scotland

1. *Introduction*

Drying is an essential, indissociable part of the smoking process. In most types of mildly smoked product the evaporation that occurs simultaneously with smoke deposition is mostly well within the range 5–25% of the initial weight, although traditional cures, such as red herring, are much more dehydrated and are combined usually with heavy salting; and some tropical smoked products undergo almost complete desiccation.

An experimental study of the drying of geometrically shaped pieces of fish in air is still in progress, but certain of the results of investigations so far reported (Jason, 1958b) are applicable to the evaporation of moisture during the smoking process. The picture at present seems substantially as follows.

2. *Constant-Rate Period*

There is a succession of phases during the drying process which can be grouped into the *constant-rate period,* during which evaporation of so-called "free moisture" occurs from the surface, after which drying enters the *falling-rate period.* During the constant-rate period, the rate of evaporation depends on the air velocity, the partial pressures of water vapor at the surface (p_s) and in the air (p_a), the shape and surface area of the fish and the direction of the air stream. A careful and detailed study of the drying process has, however, revealed that the initial period in such nonoily fish as cod consists, not of a single constant-rate period, but of a succession of several short but distinct periods in each of which the gradient dW/dt of the curve of weight W plotted against time t is constant (Fig. 5). The existence of the separate periods is a consequence of differing local rates of evaporation resulting from geometrical effects.

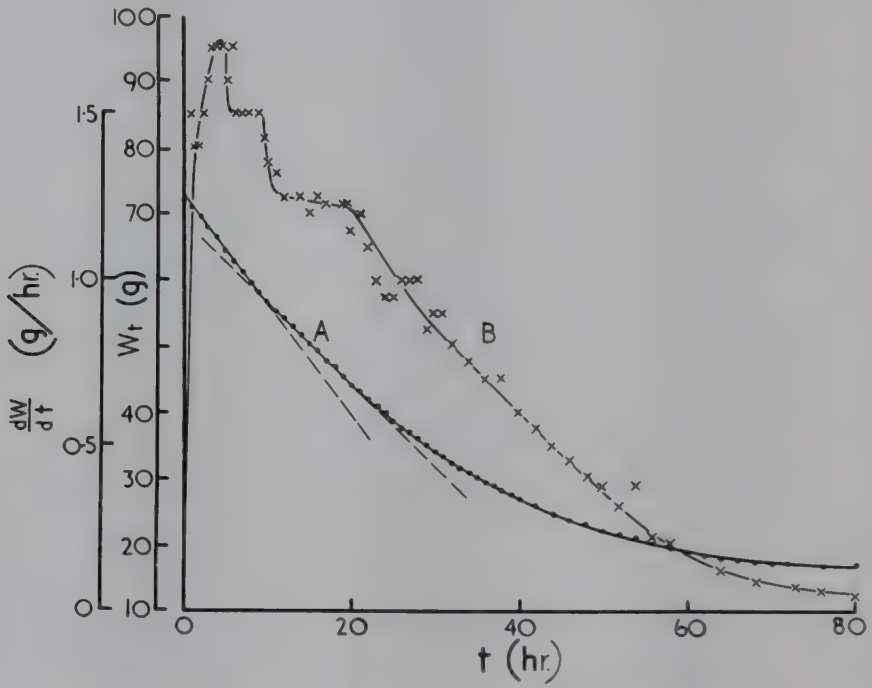


FIG. 5. Initial drying behavior of cod fillet piece 10 × 5 × 1.5 cm. exposed to air stream of velocity 30 cm./sec. parallel to 10 cm. edges. Dry-bulb temperature 30°C.; wet-bulb temperature 18°C. Curve A: weight as a function of time; curve B: rate of drying as a function of time.

Under practical conditions, however, the constant-rate period may be regarded as being one in which there is a uniform rate of evaporation. It is a sufficiently good approximation to state that this rate of evaporation is proportional to the surface area A, to the wet-bulb depression $\theta_a - \theta_w$ (Fig. 6), and to the 0.77th power of the air velocity u. This relationship is expressed in the equation

$$\frac{dW}{dt} = 1.65 \times 10^{-8} A\,(\theta_a - \theta_w)\,u^{0.77} \tag{7}$$

where θ_a is the air temperature, θ_w is the wet bulb temperature, and all quantities are expressed in c.g.s. units.

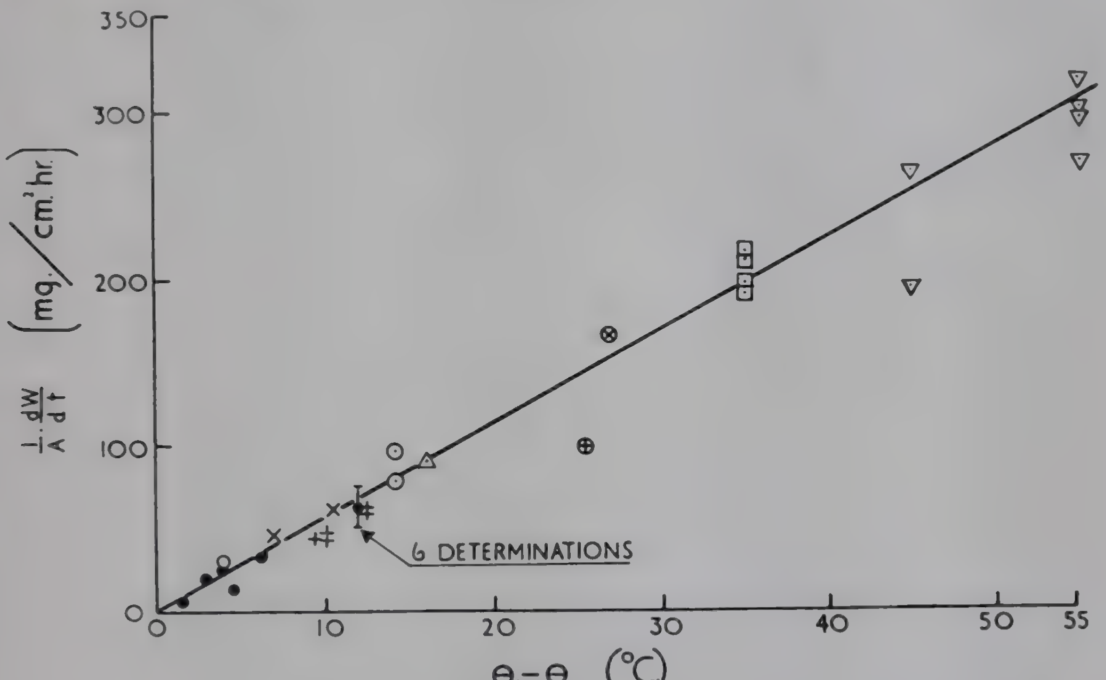


FIG. 6. Effect of wet-bulb depression on rate of drying per unit area of cod fillet pieces exposed to air stream of velocity 366 cm./sec. at various dry-bulb temperatures. Symbols: ○ 20°C.; × 25°C.; ● 30°C.; + 40°C.; △ 50°C.; ⊙ 60°C.; ⊕ 70°C.; ⊗ 80°C.; ⊡ 90°C.; ▽ 100°C.

The duration of the constant-rate period t_c is related to the rate of evaporation per unit area and to the effective diffusion constant D, the thickness $2c$, the initial concentration C_0 and equilibrium concentration C_e of water in the fish muscle, by the expression

$$\frac{1}{A}\,\frac{dW}{dt} = \frac{D\,(C_0 - C_e)}{c} \Big/ \left\{ \frac{Dt_c}{c^2} + \frac{1}{3} + \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-\frac{n^2\pi^2 Dt_c}{c^2}\right) \right\} \tag{8}$$

It will be observed that the rate of evaporation per unit area is independent of the air temperature and that the duration of the constant-rate period depends upon the temperature only insofar as it affects the diffusion constant (Fig. 7).

For practical shapes of whole fish, split fish, or fish fillets, the duration of the constant-rate period may be roughly assessed by measuring the

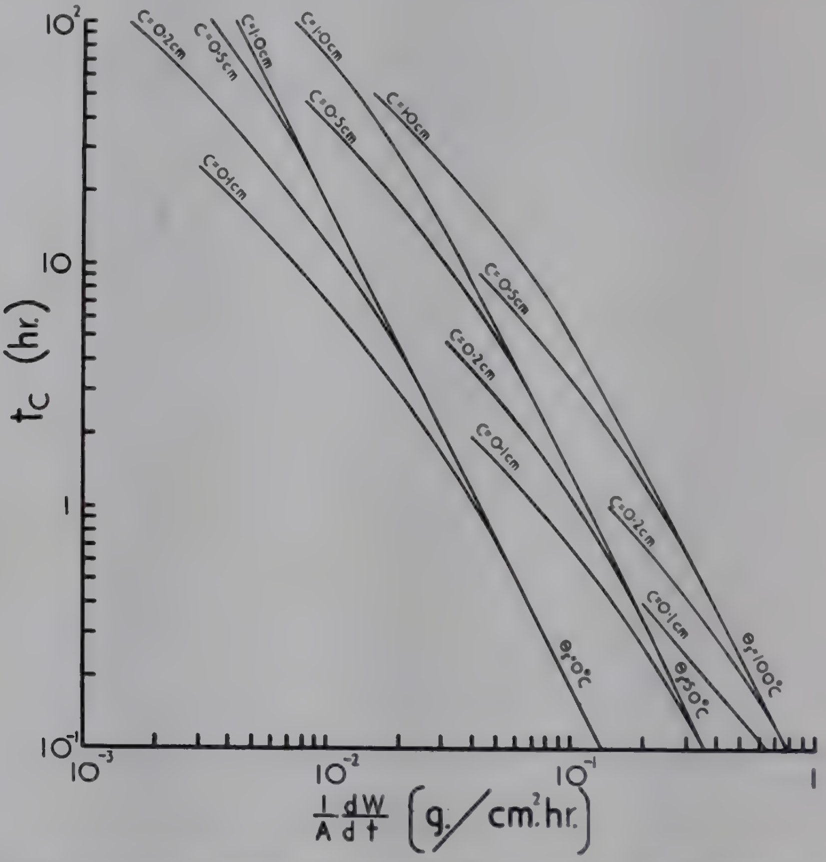


FIG. 7. Relationship between duration of constant-rate period and rate of evaporation per unit area at surface temperatures θ_s of 0°, 50°, 100°C. for cod muscle slabs of half-thickness $c = 0.1, 0.2, 0.5, 1.0$ cm.

thicknesses $2c_i$ at r equally spaced points in the plane of the sagittal section, finding the average value of the effective thickness $2c_{\text{eff}}$, thus,

$$\frac{1}{c_{\text{eff}}} = \left(\frac{1}{r} \sum_{i=1}^{r} \frac{1}{c^2{}_i} \right)^{1/2} \qquad (9)$$

and substituting in equation (8).

For nonfatty white fish fillets, a typical value of t_c for an air temperature of 30°C., a relative humidity of 50% and an air velocity of 1.5 m./sec. is 5 hr. In the case of fairly fat herrings split for kippering, the value of D is considerably less than that for white fish and leads to a much lower value for t_c; for example, under the above conditions t_c might be as little as half an hour.

3. *Falling-Rate Period*

The termination of the constant-rate period is followed by a rapid decline in the drying rate which becomes negligibly small as the moisture content of the fish approaches an equilibrium corresponding to the particular relative humidity in the air. If, for the moment, the constant-rate period is considered to be very short in duration, it is possible to calculate the weight of a given piece of fish at any time. It may be shown that if the rate of flow of water at any point within the fish muscle is proportional to the product of the diffusion constant and the concentration gradient, then the form of the falling-rate curve is expressed by the equation

$$\frac{W_t - W_e}{W_0 - W_e} = \left(\frac{8}{\pi^2}\right)^3 \left\{e^{-t/\tau} + \frac{1}{9} e^{-9t/\tau} + \frac{1}{25} e^{-25t/\tau} + \right\} \quad (10)$$

where W_t is the weight at any time t, W_0 is the initial weight, W_e is the equilibrium weight and τ is the drying time-constant, which for a rectangular slab of dimensions $2a$, $2b$, $2c$ is,

$$\tau = 4/\pi^2 D(a^{-2} + b^{-2} + c^{-2}) \quad (11)$$

where τ has the dimension of time.

For times greater than 0.2 τ, the use of only the first term in the series on the right-hand side of Eq. 10 introduces an error of less than 2%, so that the expression for the unaccomplished change in weight becomes

$$W_t - W_e = \left(\frac{8}{\pi^2}\right)^3 (W_0 - W_e)\, e^{-(t-t_c)/\tau} \quad (12)$$

A plot of ln $(W_t - W_e)$ against t will, therefore, give a straight line of slope $1/\tau$ for $t \geqslant 0.2\ \tau$.

In practice it is observed that the drying curve plotted in this way consists of two straight lines, the transition from one line to the other occurring at a moisture concentration of about 0.1 g. water per gram nonaqueous material (Fig. 8). There are, therefore, two drying time-constants τ_{I} and τ_{II} associated with each of these phases of the falling-rate period and corresponding to two diffusion constants D_{I} and D_{II}, D_{I} being several times as large as D_{II} in the range of temperatures normally obtaining. The transition between the two phases, which can be associated with the uncovering of the unimolecular layer of water covering the protein molecules, does not enter normally into most smoking processes, which fall within the bounds of the constant-rate period and the first phase of the falling-rate period.

Air velocity and relative humidity have no influence on the rate of diffusion of water in fish muscle, and, therefore, on the rate of drying during the falling-rate period, except insofar as they affect the temperature of the muscle. Relative humidity will, however, affect the equilibrium water content.

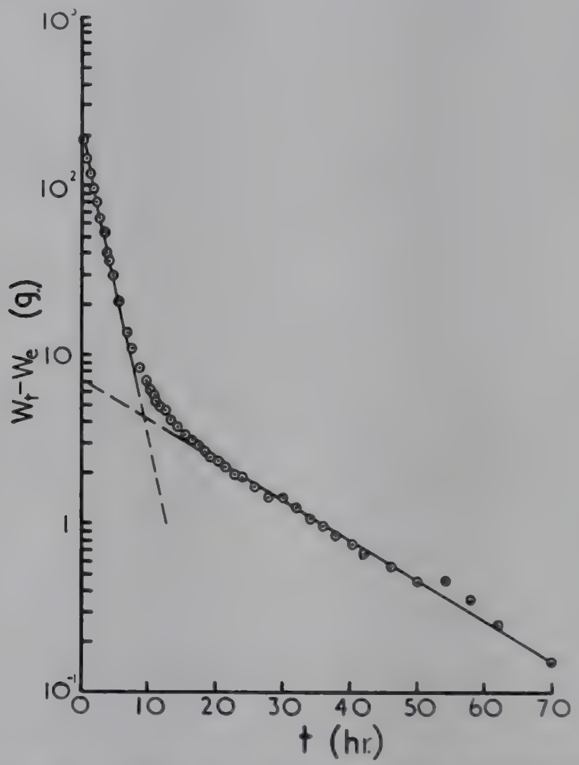


FIG. 8. Unaccomplished change in weight of water remaining in cod fillet piece 10 × 5 × 0.6 cm. as function of time. Dry-bulb temperature 35°C.; wet-bulb temperature 20.3°C.; air velocity 366 cm./sec.

Temperature has a considerable influence on the rate of drying because the diffusion coefficient depends on the thermal energy of the water molecules. The variation of both D_i and D_{ii} with absolute temperature T is of the form

$$D = D_0 \exp(-E/RT) \qquad (13)$$

where D_0 is a constant, E is the energy of activation for diffusion, and R is the gas constant. For cod muscle the value of D_0 and E for the first phase are 0.54 cm.^{2}/sec. and 7200 cal./mole, and for the second phase the corresponding values are approximately 0.7 cm.^{2}/sec. and 8500 cal./mole. The energies of activation differ significantly, but the D_0 values do not.

Values of D_i are approximately the same for all species of nonfatty fish; for fatty fish, the diffusion constant decreases with increasing fat content. Similar observations apply to D_{ii} values, which are in general approximately one-fifth of the D_i values irrespective of fat content.

Brining does not affect the initial drying characteristics appreciably, but the transition to the second phase of the falling-rate period occurs at a higher water content than in unbrined fish.

4. *Practical Calculations*

The calculation of the weight of a piece of fish at any given time is carried out in the following manner.

The total area, A, of the piece is first estimated (this will be approximately twice the projected area for a fillet) and then the effective thickness $2C_{\text{eff}}$ is obtained as indicated in Eq. 9. The rate of evaporation per unit area for the appropriate drying conditions is calculated from Eq. 8, and this enables the duration of the constant-rate period to be derived graphically from curves similar to those shown in Fig. 7. Thus the weight W_{t_c} at the end of the falling-rate period and the "unaccomplished weight loss," $W_{t_c} - W_e$ (i.e., the water which can still be removed) may be obtained if W_e is known from water relations curves. Putting $\tau = 4C_{\text{eff}}^2/\pi^2 D$, the weight W_t at any time during the falling-rate period is obtained from the expression

$$W_t - W_e = (W_{t_c} - W_e) \exp\{-(t - t_c)/\tau\} \tag{14}$$

Equation 14 is a modified form of Eq. 10 and applies when $t_c \geqslant 0.2\,\tau$. If $t << 0.2\,\tau$ Eq. 10 applies, of course.

The following is a worked example for a cod fillet piece 10 × 5 × 1.46 cm. dried at 30°C. in an air stream of velocity 150 cm./sec. and wet bulb depression 12°C. Initial weight of piece = 73.1 g.; equilibrium weight = 14.4 g.

During the constant-rate period

$$\begin{aligned}
\frac{1}{A}\frac{dW}{dt} &= 1.65 \times 10^{-8}\,(\theta_a - \theta_w)\,u^{0.77} \times 3600 \\
&= 33.6 \times 10^{-3} \text{ g./hr.} \\
\therefore t_c &= 3.6 \text{ hr. (experimental value 3.5 hr.)} \\
\frac{dW}{dt} &= 33.6 \times 10^{-3} \times 144 \\
&= 4.84 \text{ g./hr. (experimental value 4.7 g./hr.)} \\
\text{Now } (W_{t_c} - W_e) &= (73.1 - 3.6 \times 4.84) - 14.4 \\
&= 41.3 \text{ g.} \\
\text{and } \tau &= 15.9 \text{ hr. (experimental value 16.9 hr.)}
\end{aligned}$$

so that at the values of $t - t_c$ given in the tabulation below, W_t may be calculated and compared with observed values.

$t - t_c$ (hr.)	Calculated weight, W_t (g.)	Observed weight, $W_{t_{obs}}$ (g.)
0	55.7	57.6
2	50.9	51.8
4	46.1	46.2
6	42.8	42.3
8	39.4	39.4
10	36.4	36.7
15	30.5	30.2
20	26.1	26.4
25	23.0	23.4
30	20.7	21.1

III. Practical Aspects

A. Types of Product

The degrees of salting, smoking, and drying, combined with the pretreatment, trimming, cleaning, etc., which characterize various classes of smoked fish, all influence in various measure the keeping quality of the products. The main features of the principal types of smoked fish current in Britain are listed in Table IV (Cutting, 1951). Smoked products vary greatly from country to country according to the types of fish available, climatic conditions, etc. Even in a single country or district local preferences differ, and the origin of many British cured products was very localized, as evidenced by the Newcastle kippered herring, Yarmouth bloater, and "Eyemouths," "Moray Firths," and "Finnans" for increasing intensity of cure of haddocks, Arbroath "smokies," etc. It would be an impossible task to catalog all the types of smoked products made throughout the world. Therefore, the main features of the processes involved in making the products eaten in Britain, which are largely representative of those of western Europe and North America, will first be described as illustrative of the principal procedures that can be adopted, although every particular species of fish will, of course, present its own individual peçuliarities. Thus, on the Pacific coast of the United States such fish as sablefish (or black cod) and in the South Atlantic and Gulf coast mullet, kingfish, and Spanish mackerel are treated in essentially the same way as Europe treats cod and herring, while, to European tastes, more exotic products such as smoked shrimps, clams, and oysters also appear, according to local supplies and tastes (Jarvis, 1944, 1950). Furthermore, various attempts have been made to adapt these processes to warm climates (e.g., Jarvis, 1932, 1933) and tropical Africa (Johnson, 1941, 1943, 1947). Flat fishes are not often smoked, although hard-smoked salted halibut was once quite an important cured product in the United States and the smaller species are occasionally hot smoked in Scotland and skate in Germany.

In certain types of product, e.g., present-day bloaters in the United Kingdom and sprats ("brisling") and immature herring ("sild") in Norway and Sweden, the dehydration aspect of the smoking process is much more important than impregnation with smoke which, if excessive, is deleterious to the product.

Throughout the Orient, including Japan and the Philippines, there prevails a characteristic method of smoking precooked fish, which is probably Chinese in origin (Tressler, 1923; Anderson and Pedersen, 1951). Fish, or strips of fish such as bonito, or trepang (a holothurian) are first washed and then cooked in boiling salt water for a few minutes, depending on the size of the fish. After draining and removal of surface moisture, the fish are spread out in the sun to dry for an hour or so and then smoked in round bamboo baskets, with openwork bottoms, placed one above another over an opening in a stove in which a smoky fire of hardwood sawdust is burning, a tight cover being placed over the top basket. The smoking is continued for several hours, when the bottom basket is transferred to the top and the smoking carried on for a period depending on the market, 4–6 hr. being sufficient for home consumption, whereas 24 hr. or longer is required for export. The fish, which are sold by the trayful, are turned a dark chocolate color and are pared off for use in soups.

B. The Preparation of Fish for Smoke-Curing

1. *The Condition of the Raw Material*

Obviously the keeping quality of a smoked product depends to a large extent on the freshness of the raw material. Biological quality is also important.

a. Biological Quality

At certain times of the year, e.g., immediately after spawning, white fish are in poor condition, the fish being thin or its flesh soft. Pelagic fish, which pass through an annual cycle of fluctuation in fat content are usually regarded as at their best when they are fattest. North Sea herrings, for example, make excellent kippers at the height of the main summer and autumn seasons when their fat content is between 15 and 20%, but when at certain other times of the year they fall below about 10% they are less succulent, and although perfectly edible, and

Table IV
Description of the Chief Types of Smoke-Cured Fish in Western Europe

Product	Species used	Pretreatment		Salting	
		Description	Weight loss on trimming %	Method	Weight loss %
"Finnans"	Haddocks, codling	Headed, split up belly, second cut made into flesh, blood and black lining removed	22–25	Brined for 10–15 min., depending on size, in 70–80% saturated brine	0
"Pale" cure	Haddocks	As "finnans" but single cut only	22–25	Brined for 10–15 min., depending on size, in 70–80% saturated brine	0
Fillets (single)	Cod, large haddocks, saithe, tusk, redfish, monkfish, etc.	Cut from the gutted fish sometimes skinned and "lugs" (belly-walls) removed	50–55[a]	Brined for 10–15 min. according to size; usually with dye	0
Fillets ("block")	Smaller haddocks or whitings	Head and bone removed; skin on or off, double fillet	60–65	Brined for about 4 min.	0
"Smokies"	Small haddocks or whitings	Whole gutted fish headed and cleaned; tied in pairs by tails with string	20–23	Brined for about 1 hr.	0
"Reds"	Herring (also pilchards and sprats)	Whole, ungutted	0	Dry-salted in vats with about 1 salt: 2 fish for 7–8 days (if salted longer require partial desalting before smoking)	20
"Silvers"	Herring	Whole ungutted	0	Dry-salted in vats with about 1 salt: 2 fish for 10 days	20

[a] For whole cod, 40% if headless.

TABLE IV (*continued*)

		Smoking							
			Time (in hr.)				Approximate composition		
Product	Species used	Type	Old kilns	Torry kiln	Weight loss by drying on trimmed weight %	Yield of smoked product (% of landed weight)	Water %	Fat %	Salt %
"Finnans"	Haddocks, codling	Cold-smoked over sawdust fires	6–12	4–6	15–18	55–60	75	0	2–3
"Pale" cure	Haddocks	Cold-smoked over sawdust fires	4–8	2–3	12–14	62–65	75	0	2–3
Fillets (single)	Cod, large haddocks, saithe, tusk, redfish, monkfish, etc.	Cold-smoked over sawdust fires	6–12	4–6	10–15	40–45	75	0	2–3
Fillets ("block")	Smaller haddocks or whitings	Cold-smoked over sawdust fires	4–6	2–3	12–14	30–35	75	0	2–3
"Smokies"	Small haddocks or whitings	Hot-smoked in a dense smoke without excessive drying	2–3	1½	30	50–55	75	0	2–3
"Reds"	Herring (also pilchards and sprats)	Cold-smoked intermittently	[b]	[c]	20–25	65–70	40–45	15–20	14
"Silvers"	Herring	Cold-smoked over billets of wood so as to give heat rather than smoke	12	6–8	5	75–80	45	15–20	15

[b] Smoked on alternate nights for a week.

[c] Smoked for each night 3 to 4 days.

TABLE IV (*continued*)

		Pretreatment		Salting	
Product	Species used	Description	Weight loss on trimming %	Method	Weight loss %
Bloaters	Herring	Whole ungutted	0	Dry-salted in vats with about 1 salt: 2 fish for 1 night	6
Kippers	Herring	Split along back and gills and viscera removed and washed	12–24[d]	Brined for 20–25 min., usually with dye	0
Kippers for canning (mild cure)	Herring	Split along back and gills and viscera removed and washed	12–24[d]	Brined for 20–25 min., but no dye	0
Kipper fillets	Herring	Headed and boned and belly walls cut away	44–55	Brined for 10 min. usually with dye	0
Buckling	Herring	Whole, usually ungutted	0	Dry-salted overnight	6
Sardines (for canning)	Sprats (brisling) or small herring (sild)	Whole ungutted	0	Brined for 15 min.	0
Smoked eels	Fresh-water eels	Gutted and cleaned	10	(1) Dry-salted overnight or (2) Brined for 1 hr.	20–30 0
Smoked salmon	Salmon	Gutted and cleaned and backbone taken out but head left on; flesh scored in order to let in salt	15	Dry-salted 16–40 hr. (depending on size)	10
Smoked roe	Cod or ling ovaries	Washed	0	Dry-salted for 12–18 hr.	12–15

[d] Depending on roe content.

TABLE IV (*continued*)

		Smoking							
			Time (in hr.)		Weight loss by drying on trimmed weight	Yield of smoked product (% of landed weight)	Approximate composition		
Product	Species used	Type	Old kilns	Torry kiln	%		Water %	Fat %	Salt %
Bloaters	Herring	Cold-smoked over billets of wood so as to give heat rather than smoke	12	3	6	85–90	55	15–20	2–3
Kippers	Herring	Cold-smoked over sawdust fires	6–18	4–6	15–20	65	55	15–20	2–3
Kippers for canning (mild cure)	Herring	Cold-smoked over sawdust till slightest color develops	4–10	2–3	12–14	67.5	55	15–20	2–3
Kipper fillets	Herring	Cold-smoked over sawdust till slightest color develops	4–8	2–3	15	40	55	15–20	2–3
Buckling	Herring	Hot-smoked in a dense smoke	3–4	2–3	20–25	75–80	55	15–20	2–3
Sardines (for canning)	Sprats (brisling) or small herring (sild)	Hot-smoked in a thin smoke	½–1	½	10–12.5	87.5–90	55	15–20	2–3
Smoked eels	Fresh-water eels	Hot-smoked in a thin smoke	3–4	1½–2	(1) 10–15 (2) 20–25	65	40	30	4–6
Smoked salmon	Salmon	Cold-smoked using proportion of juniper wood	24–36	9–12	10	70	55	20	5
Smoked roe	Cod or ling ovaries	Cold-smoked	12	8	20–25	65–70	60	3	7

still much fatter than smoked white fish, they are regarded as inferior for this reason alone. For less sophisticated products the deficiency in oil might not matter, in fact might even be an advantage.

Herring containing more than 15% of fat are not often made into red herring. In fact, in summertime, high atmospheric temperature, combined with rapid enzymic breakdown brought about by food in the stomach, often results in perforation of the belly wall before herring are kippered.

In the case, too, of the hard drying and smoking of herring fillets in an attempt to make a product suitable for consumption in underdeveloped areas (Del Campo and Cutting, 1956), fish containing only a low percentage of fat were preferred on account of the reduced oxidation compared with more fatty batches.

b. Freshness

Fish intended for the choicest smoked products need to be handled just as carefully as for any other first-grade process, e.g., it should be kept chilled when awaiting processing. This is particularly important with small pelagic fish, such as herrings, which are not gutted at sea and therefore tend to decompose more quickly. Fish caught fairly close to the shore, including herrings, are often not even iced at all aboard the ship overnight, and for transport ashore icing ratios are often inadequate to reduce fish temperature to 32°F. and maintain it there. As a result, however carefully such fish may subsequently be smoked, the flesh will tend to be discolored in the vicinity of the belly-wall and the flavor of the product will not be of the freshest. On the other hand, if white fish are smoked before rigor mortis has set in, the appearance of the cut surface is remarkably dull and matt. The best appearance is obtained with fish which have been in ice for at least two days (Cooper and Linton, 1936).

2. *Splitting and Cleaning*

Fish for smoking should be handled carefully to avoid bruising and tearing. Guts, gills, membranes, and blood decompose more rapidly than fish flesh, and the more speedily and more completely they are removed, the better the keeping quality of the product. Such products as Yarmouth bloaters, which are made from whole ungutted herring, are the most perishable on account of their light salting and smoking. Red herrings, which are also ungutted, rely for their preservation, during smoking, on their high salt content.

Most smoked fish, however, are cut or trimmed in some way preparatory to smoking.

Hot smoked fish, such as buckling and "smokies" (see Table IV), although sometimes beheaded, are not usually split open, otherwise the suspended fish would be liable to tear under its own weight.

Gutted white fish, such as haddock and small cod, are prepared for smoking as finnans or "pales" by heading and splitting by means of a a knife from the belly all the way along the backbone to the tail fin.

There is considerable variety in the precise method of splitting. For the "pale" cure, which as the name suggests is smoked at most to a light lemon shade and is sometimes scarcely colored at all, medium-sized haddocks in Scotland are cut so that the backbone appears on the right-hand side of the split fish when viewed from the ventral aspect with the head end uppermost. To improve appearance and delay spoilage, care is taken to remove kidney and the black peritoneum by cutting and brushing either with a bunch of bristles or a revolving brush. At Aberdeen the larger fish are usually more heavily cured as finnans, in which a second cut is made into the thickest part of the flesh along the other side of the backbone, thus aiding drying as well as presenting a greater surface to the smoke. At Grimsby, the fish are cut so that the backbone is on the left-hand side. (The same principle of exposing a large surface area is employed widely, e.g., on the Upper Nile and in East Africa, where a characteristic sideways cut is given *Tilapia* species.)

Only fairly fresh fish can be made into attractive-looking split fish products. The brownish discolored belly wall of the staler fish can be removed by filleting and the fillets then smoked. Larger fish are cut so as to yield two fillets. Fish too small to yield satisfactory smoked split fish can yield quite an attractive morsel as a block fillet, cut so as to remove nearly all the edible portion of the fish in one piece. These fillets can be smoked with or without skinning. The skin is not usually eaten, but is best retained in the case of soft-fleshed species such as haddock, and also helps to identify the more valuable species. Machines have been developed that will fillet and skin various classes of fish.

For kippering, herring are usually split down the back, so that the backbone is on the left-hand side when looking at the cut surface with the head uppermost, and then gilled and gutted, leaving the head on and the belly walls intact. In most cases this operation is now done by machine, which washes away the blood and cleans the inside of the fish with running water. Other types of machine can remove head, belly walls, and backbone, and the practice is growing of smoking these kipper fillets, in which the inedible bony matter is minimized although not eliminated. The skin of herring and similar species is too thin to be removed easily by means of a knife. Salmon were formerly smoked split down the back, with the head on (this in fact was the origin of the kipper) (House and Cutting, 1956), but this, too, is now mostly smoked as fillets.

3. *Salting*

Formerly salting was an essential part of the preservative process in such a cure as red herrings. However, the salt concentration in the product has to be between 8 and 10% before there is appreciable inhibition of molds and bacteria (Shewan, 1954). In the quantities acceptable today (about 2 to 4% in the product) its preservative effect is trifling and its main function is to confer a piquant flavor as well as to improve appearance.

Fish can be salted either by packing in solid salt ("dry-salting") or immersing in a strong brine. The osmotic changes which occur are quite complex (see Reay, 1936). In dry-salting, the salt in addition to diffusing into the flesh also extracts water from the tissue, which dissolves the salt to form a saturated brine. When fish are "roused," i.e., simply mixed with salt in a pile on the floor, this brine runs away and there is an appreciable over-all reduction in weight. If dry-salted in a vat, however, by the time the fish are hard-salted (or "struck through") the saturated brine collects and ultimately covers the fish if sufficient fish and salt are available and after an initial extraction of water, brine flows back, so that there is little over-all weight change finally when equilibrium is established. Herrings for "redding" are salted in this way for 7–8 days if they are to be smoked immediately, taking up about 10–12% of salt in the process and losing about 15% by weight. The product after smoking should contain about 14% of salt and 40–45% of water, which practically corresponds to a saturated solution [26.4% at 16°C. (60°F.)] in the tissues. Alternatively, herring intended for "redding" are often stored under the brine for several months, and when equilibrium is eventually established, they have become permeated with a saturated salt solution. Before they are smoked, such herrings have to be partially desalted by steeping in fresh water for up to 24 hr. with at least one change of water, otherwise salt would crystallize as a white power on the surface of the fish as it dried during the smoking process.

If fish are salted by dipping in brine ("brining"), there is no appreciable over-all change in weight in a 70–80% saturated solution, provided, of course, that it is kept up to strength. In more concentrated brines there can be a per cent or two net loss of weight and in weaker brines a gain in weight. Brining is a much quicker method of imparting salt than dry-salting, probably because the area of contact with the flesh is so much greater in the case of a liquid, and it has been widely adopted for effecting the mild treatments favored today. Thus, to take an example, eels of 1/2–3/4 lb. weight attain a salt content of 4 to 6% without change of weight after an hour's immersion in a nearly saturated brine, while in dry salt the same salt content is reached only after 12 to 18 hr., with about 20–30% weight loss. Yarmouth bloaters are a cure in which dry-salting is preferable to brining, because they need to lose a certain amount of water during processing, while remaining silvery in color, so that they cannot be dried too much by exposure to smoke. They are therefore usually "roused" overnight, losing about 5 to 6% by weight, while a further 5–6% is lost by evaporation in the kiln. Brining would result in practically no loss of weight, so that the required 10–12% would all have to be lost by smoking. Buckling are often dry-salted similarly for the same reason. If brined, they require 1–2 hr. immersion in 100% saturated brine. In Germany they are sometimes salted by sprinkling during packing with solid salt sufficient to bring the over-all salt content to about 3%, which is supposed to result in a brighter-looking product than salting before smoking.

Split fish, such as kippers and finnans, pick up salt from brine much more quickly than whole fish because they are thinner and present double the surface area, and moreover salt penetrates a cut surface more quickly than it can through skin (Reay, 1936).

Smallish haddock when "block filleted" (i.e., one fillet per fish) require only about 4 min. in, say, 80% brine to absorb the required 2–3% of salt. Larger haddocks or codling, split for finnans or "single filleted" (2 fillets per fish), required 10–15 min., depending on size. The tail end of fillets and the thinner side opposite the backbone of kippers or finnans are always saltier than the thicker portions. A certain amount of equilibration of salt content takes place as the product is kept (House and Cutting, 1956). The drying that occurs during smoking increases the concentration of salt in the flesh. So does cooking by grilling or frying, but stewing, of course, reduces saltiness.

The penetration of salt is retarded by oil in the fish. Thus, haddocks for smokies are brined for about 1/2 hr., while herring for buckling are given 1–2 hr. for about the same salt uptake. Similarly, fatty herring require 20–30 min. brining, which is at least twice as long as required for haddocks of similar size. Immersing large batches of fish in a vat of brine does not result in uniform treatment. Intermittent agitation of the charge is desirable. For controlled and even salting, a continuous mechanical brining process is essential.

A brine strength of between 70 and 80% seems to yield the most attractive product. In a 90–100% saturated brine there is a 2–3% loss of weight in absorbing 2–3% of salt and a rather less glossy cut surface results, as well as crystallization of salt as a white powder on exposed parts, such as the gill covers of kippers. Unbrined fish are extremely dull, rough, and matt in appearance. The weaker the brine, the longer the time of immersion required and, in a 50% brine, the split fish tend to swell a little, gaining 2–3% in weight and again appearing somewhat dull.

The brine is depleted as a result of salt absorbed by the fish, as well as by dilution with water adhering to the fish. It is usually necessary to add solid salt from time to time to maintain the brine strength at the desired figure. It is not practicable under commercial conditions to "top up" with saturated brine on account of the large volumes of 100% brine required to keep a brine strength up at 80%. Thorough stirring is essential to ensure that the added salt dissolves instead of settling at the bottom of the tank. Salt, of course, does not dissolve any more easily in hot water than it does in cold.

In special cures, such as smoked salmon [which were formerly very hard-cured so as to last for months, although mild curing is now the standard practice in the the United Kingdom (House and Cutting, 1956)] and cods' roes, relatively small amounts of brown sugar and also saltpeter, even rum or whisky, are added to the pickling brine to improve the flavor. When artificial coloring is used, it is usually incorporated in the brine.

C. Smoking

1. *Types of Process*

There are two distinct types of smoking process, depending on the amount of heat to which the fish are subjected. In "cold-smoking," e.g., of kippers, bloaters, "finnan" haddocks, salmon, etc., the normal smoke temperature is not more than about 30°C. (86°F.) and the smoked fish is not even partly cooked. On the other hand, "hot-smoking," e.g., of buckling, sprats ("Kieler sprotten") and smokies, the fish are intentionally cooked in the smoke (in special kilns, which are sometimes gas-heated), the temperature of the smoke rising at times to above 100°C. (212°F.) while the flesh of the fish reaches 60°C. (140°F.). This heat treatment results in partial sterilization, although subsequent reinfection and spoilage of the cooked flesh is still quite rapid, so that the keeping quality is not noticeably enhanced.

When lightly brined split fish are subjected to the action of cold smoke produced by smoldering wood fires, the smoke constituents (discussed above in Section II, B) are deposited on exposed surfaces and simultaneously moisture evaporates (see Section II, C) resulting in about 15 to 20% loss of weight in the case of well-smoked kippers and "finnan" haddocks. As a result of both these processes of drying and smoke deposition, the typical British cold-smoked, mild-cured product is preserved in first-class condition for two or three days at ordinary atmospheric temperatures, and remains palatable for up to a week, depending on the initial freshness of the fish and the amount of smoking and drying undergone (see Table V). In this class of product the bactericidal substances absorbed from the smoke are more effective than the slight degree of drying in inhibiting the growth of microorganisms. The keeping quality, therefore, depends primarily on the extent of smoking. Very lightly smoked fish, which will also usually be only slightly dried, although delectable in flavor when really fresh, are just as perishable as fresh fish and need to be kept thoroughly chilled throughout transport and distribution to minimize spoilage. For example, kippers made from fresh herrings smoked in an experimental mechanical kiln (see Section III, C, 4c) for 1, 2, and 3 hr. at a smoke density (see Section II, A) of 0.3 optical density units per foot and absorbing, respectively, about 0.3, 0.6, and 1.0 "phenol units" (expressed as "equivalent extinction per section" of 2.7 cm. diameter with two smoked surfaces, steam distilling, and using 4-aminoantipyrene), while losing about 5, 10, and 15% of weight by evaporation, kept when stored at 20°C. (68°F.) for 2, 5, and 7 days, respectively, in acceptable condition. Similar differences were obtained with fish smoked commercially in a traditional kiln, although these did not keep quite as well, whether judged by taste panel score or the appearance of mold growth.

TABLE V
APPROXIMATE STORAGE LIFE OF MILD CURES MADE FROM FRESH FISH (IN DAYS)

Product	In first class condition		In edible condition at 60°F.
	32°F.	60°F.	
"Finnans"	4–6	2–3	4–6
"Pale" cure	4	1–2	2½–3
Fillets (single)	4–6	2–3	4–6
Fillets ("block")	4	1–2	2½–3
"Smokies"	3–4	1–2	2½–3
Bloaters	3–4	1–1½	2–2½
Kippers	4–6	2–3	5–6
Kipper fillets	4–6	2–3	5–6
Buckling	3–4	1–2	2–3
Smoked salmon	6–9	3–4	6–9

The smoking process, although not the only factor determining quality, is crucial. Obviously if other links in the processing and distribution chain have been neglected, the smoking process in itself cannot ensure that the resultant product is good, although only if it has been satisfactorily carried out can a really excellent article be obtained.

The smoky flavor and the toughening produced by drying (possibly combined with the action of formaldehyde in the smoke (Forbes and Dauphinée, 1925)) result in a characteristically palatable article, which is often consumed in preference to fresh fish. The sticky salt solution of protein on cut surfaces dries, both before and during the smoking operation, to form a glossy "pellicle" which is brownish-yellow in color, intensified by the drying, resulting from the action of the smoke chemicals.

2. *Hanging*

The split fish have to be stretched out somehow so as to ensure thorough exposure to the smoke, and practice varies considerably from place to place. Typical methods are hanging on pairs of square hooks, nailed at regular intervals along a wooden "tenter" stick or threading through the "lugs" on pointed metal "speats" (or "spits"). In the case of large "finnans," a loose hook is sometimes clipped onto the projecting backbone in order to prevent the soft flesh of the "lugs" from tearing under the weight of the fish. Fillets tend to tear if hung by hooks through the flesh. They are laid over either pairs of wooden strips or a metal loop, sometimes closed at both ends (known in Grimsby as a "banjo"). "Reds" and bloaters are "speated" through the gill and mouth with wooden or metal rods, and sprats, when hot-smoked for canning as "sardines," are threaded through the eyes on thin "speats." Buckling with heads on are sometimes threaded in pairs on sticks, with the head of one fish passing under the gill cover and out through the mouth of the other. If smoked after beheading, they can be speated through the thickest part, or else suspended by a clip on the tail, although in this case any roe is liable to drop out of the fish, and liquid exuding during the cooking process drips onto the fish below, leaving unsightly stains. Predrying such hot-smoked fish for a period of half an hour or so at a fairly low temperature, not above about 40°C. (104°F.) is desirable for its effect on toughening the flesh so that it is not so unduly softened as to tear during the subsequent stage of cooking at higher temperatures. "Arbroath smokies," which are headed and hot-smoked, are tied in pairs with string and laid over sticks. Short sticks can be inserted in the gut cavities to keep the fish open and thus ensure thorough exposure to the smoke. Large whole split fish, such as salmon, are suspended by the tail and kept flat open during smoking by means of sticks or metal skewers threaded through the flesh. Salmon fillets are suspended by a loop of twine through a hole made in the "lug" just under the "shoulder bone."

Many of these devices leave unsightly holes in the fish, and wooden tenter sticks, metal speats, etc., are difficult to keep clean. Fillets have wet, unsmoked patches where they touch the stick. Furthermore, the operation of hanging and unhanging is manually laborious, particularly with small fish. Only in Norway has any attempt been made to mechanize the threading on rods of even such tiny fish as sprats and immature herring (Hansen, 1952).

Fish can be smoked satisfactorily on wire gauze trays, provided that the mesh does not mark the skin or flesh excessively, and this practice is quite normal in North America, the fish being tilted a little so that smoke rising upward contacts both sides. With a mechanical kiln delivering a horizontal flow of smoke, tray smoking would seem just as convenient as hanging vertically, and more easily adaptable to mechanization.

3. *The Production of Smoke*

For a normal fire for cold smoking, a layer of "chips," or coarse shavings (known as "mush" in Grimsby), is first laid down, with a layer of sawdust on top, which collapses continuously as undermined by the burning of the underlying chips and thus damps down the flames, producing smoke rather than heat.

The type of wood burnt varies greatly from place to place, depending on what is available, and practically anything can in fact be used. Shavings and sawdust of hardwoods, particularly oak, are generally preferred to those of soft, coniferous woods, such as fir, which give a marked color but are apt to impart a resinous flavor to the fish. Teak and pitch-pine confer a rather acrid flavor. Mahogany, redwood, and Oregon pine give a good color and passable flavor (Shewan, 1945). Driftwood, hickory, cedar, eucalyptus woods, and rice husks are used in some parts of the world as a source of smoke. A certain amount of brown ("foggy") peat is sometimes burnt with the sawdust to give a characteristic flavor to some cures of white fish, although fish are not now smoked entirely with peat, as was once the case from the origin of "finnan" haddocks for example in domestic chimneys.

Salmon is often smoked over fires containing a little juniper wood in addition to oak dust, which confers a slightly piquant flavor.

However, tasting tests have shown that the type of wood used has less effect on flavor than has been commonly supposed (Sidaway, 1944). It is more important that the quantity of smoke applied should be adequate for preservation.

Sawdust is usually available as a by-product of sawmilling, although it is also possible to produce it by controlled grinding of wood. As it is normally delivered, there is a considerable variation in particle size from about 1/8 in. down to less than 30 mesh, in addition to containing stray pieces of much larger size, foreign bodies, etc. As the other extreme, "wood flour" formed by the abrasive treatment of wood is so fine that it can be lifted into the air in a draft.

The water content of sawdust varies considerably. Depending on how green it was when sawn, hardwood often contains 40–50% of moisture, at which it will still burn satisfactorily. The softwood sawdust met with has usually been between 25 and 30%. Really dry sawdust will usually be found to contain about 15%, depending on the state of equilibrium with atmospheric humidity. A capacitance-inductance meter has given promising results for quick determination of the moisture content of sawdust.

It is practically impossible to tell from microscopic examination of sawdust the type of wood from which it was produced. However, it is possible, given wood chips revealing structure, to apply the United Kingdom Department of Scientific and Industrial Research Forest Products Laboratory "lens key" for the identification of timbers.

Various crude chemical tests can, however, be used to differentiate softwood from hardwood sawdusts. Thus, oxidizing agents, such as chlorine water or alkaline potassium permanganate solution (subsequently acidified to remove manganese dioxide), cause hardwoods to turn red, but not softwoods. Again, treatment with ferric chloride causes the tannins in oak to turn black, although some varieties of oak do not contain a great deal of tannin while some chestnuts contain appreciable quantities.

Sawdust is heavily contaminated with molds and it should, therefore, be kept away from places where fish are being brined, tentered, etc. A number of attempts have been made to mechanize the production of smoke as an improvement on the traditional fire (e.g., Harrison and Roach, 1948); there also have been several commercial attempts, but they have claimed more success in bacon smoking, the requirements of which are somewhat different. Thus a British invention (Collier, 1957) relies on water being added continuously to damp down the sawdust, which would probably result in an excessively high humidity in a fish-smoking kiln, while another type from the United States (Anonymous, 1950) seems more adapted to the semihot smoking of small pieces of bacon at a high humidity with little or no ventilation and very little drying. There have even been claims about a process depending on smoke produced when a friction wheel bears on a log of wood (Anonymous, 1956; Husaini and Cooper, 1957). However, the most promising contrivance at present is based on distilling off volatile components of sawdust without combustion proper by flotation in air at a controlled temperature (Nicol, 1957). Under conditions of "fluidization," production of smoke, which first appears at about 250°C. is maintained continuously by feeding in sawdust while the temperature of the air stream is kept at about 350° to 400°C. At about 500°C. the smoke catches fire. In the center of the glowing portion of a traditional fire a temperature of about 800°C. is attained, which falls to little above atmospheric at the outside of the heap. Considerable chemical engineering difficulties have to be overcome in developing a smoothly running piece of equipment along these lines. The smoke produced has somewhat different chemical and physical properties from "normal" smoke, but it is hoped that the flavor, color, and preservative effect will be acceptable. However, such mechanical smoke producers are more likely to be used in conjunction with mechanical kilns (Section III, C. 4, c) than to be applied to traditional kilns.

4. *Smoking the Fish*

a. CHIMNEY KILNS

Fish is still mostly smoked in a manner but little removed from its Bronze Age predecessors. Although under primitive conditions, or on a small scale, fish can be smoked merely by hanging over open fires, the large-scale smoking industries which have been built up have demanded regular forms of smokehouse. Mostly, the sticks, etc., carrying the fish are hung in the natural vertical up-draft produced by the heat of fires burning on the floor. In this chimney, the fish are kept for anything from a few hours to a week (for "red" herrings), but typically the smoking process takes place overnight. The chimney itself (dignified by a variety of names, such as "kiln" in Scotland, "oven" in Germany and Norway, particularly for hot-smoking, and "smoke-hole" in Grimsby) can vary enormously in dimensions and elaboration. At one end of the scale a disused barrel will serve; at the other end, substantial brick buildings may be erected.

Considerable practice and skill are required to produce a satisfactory result. The principal problem is to control the process in such a way as to secure reasonable uniformity of product. Obviously the temperature, relative humidity, rate of air flow ("draft"), and smoke intensity above an open fire are subject to wide fluctuations and considerable perturbations, as a result of the interplay of a number of factors, such as outside weather conditions, size and construction of kiln and of the factory housing it, type and moisture content of sawdust, etc. In any case, natural convection is fitful and its vagaries difficult to predict and control. The "art" of smoking proceeds from the rule-of-thumb knowledge of how to proceed so as to balance out the effect of some of the factors producing variation (Duthie, 1911). It usually involves taking out the sticks of fish and turning them round at least once during the smoking, and removing those nearest the fires which are finished first, as judged by color and "feel," and moving down the upper ones. All this is a laborious, dirty, time-consuming proces, and fish often fall off into the ashes.

Furthermore, the measure of control effected under present-day conditions is often rather inadequate. Thus, in a typical kipper kiln recently investigated in operation, smoke temperatures over the fish fluctuated mostly between 65° and 75°F., (cf. 85°F. regarded as optimal) and occasionally soared to between 95° and 140°F. for short periods. Relative humidity was in the region of 80% of saturation (inlet air temperature being about 40°F. on the night in question). Air velocity varied from practically nil to as high as 300 ft. per minute in gusts, and on occassions in some parts of the kiln a down-draft was registered. Smoke density, too, fluctuated throughout an 8-hr. smoking period between < 0.05 to > 0.5 optical density units per foot (see Section II, A, 4b). The losses of weight are also variable. On one occasion, finnan haddocks in a battery of four small kilns under careful supervision lost between 10 and 18% in from 5½ to 11½ hr., but not respectively. The total smoke treatment and corresponding variation in "phenol" uptake can vary by a factor of 10 in fish from the same batch unloaded after between, say, 1 and 12 hr. in the kiln.

During hot smoking, uniformity of conditions is particularly difficult to achieve in traditional kilns. In the case of sprats, etc., smoked as "sardines," frames of fish on sticks have to be turned round practically continuously, and moved up and down in the kiln, and in spite of all this, it is not unknown for the entire kiln full of fish to catch fire as a result of too much fat dropping onto the fires during the cooking. In the case of buckling herrings, as produced on Bornholm, the fires are either raked continuously across the floor so as to distribute the heat evenly or else moved to and fro on special trolleys. Real "artists" used to take inordinate trouble to counteract the capricious movement of the smoke. One such described in 1883 how in making "The Real Aberdeen Finnan Haddie" [in contradistinction to the abominable imitations then being produced in Hull, and even in Aberdeen itself, from trawled fish (see Cutting, 1955)], the fish had to be shifted "not under four times," and if the draft were bad, "not under a dozen times." Although there is no gainsaying this painstaking skill, it was essentially a domestic system, and as such had to adapt itself to the age of mass production, in which such attention could no longer be lavished on each individual fish. As a result, the standards of uniformity and quality of smoked fish today are necessarily laxer than those of the pioneers.

b. USE OF ARTIFICIAL COLORING

One way of camouflaging lack of uniformity of appearance in a batch was to color the fish artificially before they enter the kiln by incorporating suitable dyestuffs in the brine dip. Vegetable dyes such as saffron and annatto had long been used in this way (Stevenson, 1899), and in the United Kingdom kippers and kipper fillets and smoked white fish fillets ("yellow fish") are now practically universally "colored," although not usually the more aristocratic "finnans." The dyestuffs used were formerly mixtures of "Orange I," "Tartrazine" (yellow), and "Amaranth" (red) for white fish, with the addition of "Brown FK" for kippers (Syme, 1957), but since 1957 "Orange I" has been removed from the United Kingdom permitted list (Statutory Instruments, 1957), presumably on the grounds of potentially carcinogenic properties, and manufacturers must, therefore, be substituting one of the two permitted orange colors ("Orange G" or "Orange RN") to produce the same tints. In some states of the United States, dyed fish is forbidden as deceptive. In the United Kingdom its principal effects have been

(a) to facilitate less close control over the process, and therefore over the uniformity of treatment and keeping quality of the product;

(b) to permit the evolution of less smoky and dried products without greatly affecting the superficial appearance (color);

(c) as a result, keeping quality has been appreciably shortened, so that the product is now much more perishable than, say 30–40 years ago, although this is by no means generally realized;

(d) consequently, people have become accustomed to milder curing (in any case an inevitable historical trend) and have mostly lost the liking for the smoky-flavored and tougher products with an attractive natural color of the predyeing era;

(e) as the "coal-tar" colors are more lurid, people today would probably not willingly accept the "old-fashioned" product (e.g., kipper) on its appearance alone;

(f) as a result of the production of inferior dyed products and ignorance in the trade and consuming public of their relatively poor keeping quality, an appreciable proportion of the smoked fish on sale in the shops is by no means of a quality to encourage people to come back and buy more.

The above chain of cause and effect is the background of the nostalgic lament, regularly expressed, to the effect that "smoked fish are not what they used to be." This is the inevitable result of trying to adapt a medieval technique to factory production in the 20th century. The remedy is to define realistic standards and limits of quality related to some better procedure of controlling quality than is possible with traditional kilns (Cutting and Burgess, 1959).

c. Mechanical Kilns

During the last quarter century various attempts have been made to develop mechanical kilns of various types to meet the requirements of certain of the products. Thus in Canada (Cooper, 1938; Linton and Wood, 1944; Lantz, 1949) the United States (Anderson and Pedersen, 1948), and the United Kingdom (Hardy and Cutting, 1942; Cutting, 1950), government workers have produced designs of kilns which, it is variously claimed, are more controllable, more uniform, give a cleaner product, prevent wastage of fish, and involve less labor. A handful of basic designs has been quite widely adopted with varying degree of completeness and success. There have also been a number of mostly amateurish commercial attempts, often patented, to improve the process, e.g., by means of a continuous conveyor system (Robinson, 1933), but, at least so far as Britain is concerned, without durable success. From time to time, too, the technical food press carries an article on some industrial concern which is using another new type of kiln, which on closer inspection is seen to contain little new or remarkable (e.g., Anonymous, 1939; Ghizzoni, 1956). In Germany, however, continuous mechanical "ovens" have been widely used for the hot-smoking of "Bücklinge" (Myles *et al.*, 1945), although in at least one factory at Bremerhaven this appears to have been abandoned (Jones, 1957). In Denmark, the responsible view is that the product of mechanical kilns so far "cannot compete in flavor and texture with smoked products made in the traditional manner" as at Bornholm (Bramsnaes and Petersen, 1953). In Norway, on the other hand, the possibly less exacting requirements of slightly smoking, drying, and cooking sprats prior to canning as brisling (Børresen, 1952; Kverneland, 1953) has been practically universally mechanized by a continuous trolley and tunnel process (Kvaerner Brug and Bergers, 1938; Knutsen, 1952), or one employing a moving belt, although not without some criticism (Egeland, 1952; Jacobsen, 1952).

The prime reason for the comparative failure of many attempts to provide mechanical kilns in the past is that they have been designed either by practical fish smokers without the necessary grasp of engineering, or by engineers without a proper specification of what conditions were to be provided. Even the government workers' designs had, not unnaturally, to be modified in the light of practical use. In fact, until much of the necessary background knowledge now still being obtained, as described in Section II, can be assimilated into the practical smoking process, it will not be possible to give a precise specification which will unfailingly yield a product of predictable qualities. In spite of this, however, quite enough is already known in a rough-and-ready way to improve vastly upon average traditional methods by selecting one or another of the officially recommended kilns, and as far as the United Kingdom is concerned there is growing interest in mechanizing the production of smoked fish (see Syme, 1957).

d. Smoke Concentrates

Attempts have been made from time to time to replace the laborious and time-consuming procedure of hanging fish in smoke by means of a short dip in some "smoke concentrate." Improved antioxidant effect has also been claimed for such treatment (Watts and Faulkner, 1954).

In the first place, although smoking as a method of imparting chemical preservatives is hallowed by tradition, treatment by dipping would almost certainly not be permissible under the Food and Drugs legislation of the United Kingdom at least, at present. Evidence would have to be produced to show that the composition of the product was not significantly different from what is customary. In France, however, it is claimed that a "smoke oil" ("Fumeol") made by spraying atomized edible oil through smoke, has been accepted by the authorities (Guinot, 1950). It would be expected that any fraction of smoke condensate (of which "pyroligneous acid" produced from the dry distillation of wood and containing appreciable amounts of known toxic substances, such as methyl alcohol, is the crudest example) would be markedly different in chemical composition from that deposited, almost exclusively from the vapor fraction (see Section II, A, 4, a), on fish by normal smoke.

It is, of course, necessary to dry the dipped product if it is in any way to resemble the customary accepted products and, in the author's experience, both appearance and flavor of all experimentally dipped products are noticeably different from the customarily accepted products, a view also subscribed to by Jarvis (1950). Nevertheless, it is possible to envisage a dip being evolved that is acceptable on grounds of palatability and appearance without being inimical to health. This dip could, in principle, consist of an entirely synthetic mixture and as long ago as the 1930's, Prof. Harden F. Taylor, then President of the Atlantic Coast Fisheries, described such a mixture which he regarded as very successful, although it was not taken up, no doubt in view of the possible difficulties with the United States Pure Food Laws.

D. Post-Smoking Treatment

After removal from the kiln, smoked fish are usually allowed to cool somehow before grading and packing. Cold-smoked fish can lose an additional 1–2% of weight by further evaporation at this stage, and even up to 5% if left hanging overnight in dry conditions. Packing while still warm, however, results in deposition of moisture on the insides of wrappers, etc., which is conducive to premature mold growth.

Smoked fish in the United Kingdom is usually packed in non-returnable wooden boxes of one-stone capacity. It is becoming common practice to wrap kippers in pairs in regenerated viscose film as a prepackaging enhancing hygiene as well as permitting branding and labeling.

Smoked fish can also be successfully frozen and cold stored, although the keeping quality at a given temperature is not as good as that of unsmoked fish (Reay *et al.*, 1950). Cold storage is, however, often misunderstood or abused in the case of smoked fatty fish, and all too often bad flavors in kippers can be attributed to rancidity deriving from bad practice prior to or during cold storage. The practice is also growing of dispatching to retailers in the frozen state, which obviously helps to minimize spoilage prior to consumption.

However, the direct use of ice, the simplest and cheapest common form of refrigeration, is precluded in the case of "dry fish." As a result, the average temperatures of smoked fish during transport and distribution are considerably higher than that of wet fish. It is imperative, if the more mildly cured smoked products of today are to be prevented from developing "off" flavors before they are consumed, that the advantage of refrigeration be applied more systematically all along the chain of distribution.

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Salting of Herring

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I. Introduction

The salting of herring is intimately connected with the development of marine fishing. Comparatively large quantities had to be preserved not only on shore, but also out at sea. In the twelfth and thirteenth centuries, production of herring in the North and Baltic Seas was already on a rather large scale (Noël de la Morinière, 1817; Samuel, 1918; Cutting, 1955).

The salting of herring was probably first practiced in Scotland in the eighth century. Afterwards, in the fourteenth to sixteenth centuries, this method was improved by the Dutch and Scotch and also by the Russians, working independently (Noël de la Morinière, 1817; Dosipheus, 1833; Maksimov, 1872; Samuel, 1918; Jarvis, 1950; Cutting, 1955).

In Russia, the barrel salting of herring was originally employed in the White Sea area by monks of the Solovetsky Monastery (fifteenth century). Whole herring were salted with small quantities of salt. The fish were packed in barrels in regular layers, and each layer of herring was sprinkled with salt.

Contrary to the methods used in the countries of Western Europe, a barrel of rather small size, containing 10 kg., was used for the salting of herring. Such a barrel was called "seldyanka" (Danilevsky, 1862). After being filled, the barrels were tightly sealed to prevent spoilage and possibly also to achieve better ripening. They were then buried in the ground, which kept them at an almost constant temperature of 0°C. In later times, special vaults were dug in the ground for this purpose. During the summer season these were cooled by ice. Salted herring of the Solovetsky

Monastery were distinguished by very good quality and, judging by their method of preparation, were similar to the Dutch, which in Western Europe have always been considered the best. The so-called Anzersky herring, from the Gulf of Anzersky in the Solovetsky group of islands in the western part of the White Sea, off the city of Kem, were also of especially good quality (Dosithei, 1833; Semenov, 1859; Danilevsky, 1862; Maksimov, 1872; Minder, 1948b).

If the salted fish did not have a specific odor and soft consistency, the Russians were unwilling to buy such fish, claiming that the "fish was not ready," that is, according to the terminology of our time, had not ripened. Up to the end of the eighteenth century, in the diet of the Tsar's family and well-to-do classes of the population of Russia, the salted herring of foreign import (even Dutch and Scotch) were used very little. At this time, the salted fish of domestic preparation was particularly valued and most readily purchased (Chulkov, 1781–1788; Semenov, 1859; Kostomarov, 1862; Zabelin, 1872).

In the eighteenth century two distinct branches of the herring industry emerged, one based on catching the fattening herring in the open sea, and the other on spawning herring coming in large shoals to the coast and even entering the rivers; the vats or bins[1] and the pile type of salting were employed.

II. Methods of Salting Fish

Salting is a method of preservation based on the penetration of table salt into the tissues, and governed by various physical and chemical factors such as diffusion, osmosis, and a series of complicated chemical and biochemical processes associated with changes in various constituents (chiefly protein) of the fish.

Salting starts the moment the fish surface comes into contact with salt. The condition of the salt does not matter, whether in crystals or in solution. Under practical conditions the salt treatment is initiated when the vat, barrel, or other container is filled with fish and salt. The end of the salting process is the moment when all the fish have reached the required salinity and acquired the appropriate taste, consistency, and odor.

Japanese researchers (Murata and Ohoishi, 1953) established the following relationship, which describes the concentration limit to which the fish must be salted in order to keep:

$$\frac{S}{W - 35} \times 100 = 50$$

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[1] In the Soviet Union a square vat of very large size is called a bin.

where S is the content of table salt in the meat (in %), and W is the content of water, free and bound, in the meat of the salted fish (in %).

Upon attaining the limit (characterized by the number 50), the bacterial activity (decomposition) in the meat of the fish has been stopped.

Different procedures are in use for the salting of herring, the selection depending upon the climatic conditions, character of the industry, and the organization of the salted herring trade specific to each country.

The most common procedure is to employ containers such as vats, bins, and barrels (Voskresensky, 1958, 1960). The vat has been widely used by the fish industry of many countries since the middle of the nineteenth century. In Russia, for example, this coincided with the period when, particularly on the Volga, the Astrakhan fish industrialists began to pack herring in salt in massive quantities. This sharply decreased the rendering of fat from the fish. Norway considerably expanded her fisheries in the fjords in order to salt herring. Partially subterranean vats were used, easy to assemble and dismantle. This is important in areas where the herring does not regularly approach the shore.

The salting of fish in vats was quite a favored method in some countries for the following reasons:

(1) In the case of large fisheries, the migration usually is of short duration and massive character, especially during the catch of spawning herring; in order to process quickly large quantities of fish (about 100,000 lb. per day and per enterprise), simple and spacious installations are indispensable. Vats meet these requirements effectively.

(2) In the majority of cases, especially in areas with a warm climate, it is necessary during the salting to chill the fish with ice. In vat-type salting, it is easier to do this by interspersing the fish layers not only with salt but with ice; in barrel-type salting this is almost impossible.

(3) With the arrival of fish in large quantities, it is quicker to salt in vats than in barrels. Unit consumption of labor in a vat salting process is less than when barrels are used.

The drawbacks of vat salting are the unequal degree of preservation, due to the height of the vat, and the pressure exerted on the fish during salting. Both of these are serious, especially in the salting of fat fish with tender meat.

During recent years, with the greater mastery of herring fishing in the oceans, vat-type salting is gradually losing its prior significance in both the U.S.S.R. and other countries. It is being replaced by salting in barrels. The difficulty of mechanizing the packing of raw fish in the barrel and the low productivity of labor during this operation are the basic factors holding back the introduction of a barrel-type salting of herring in fish factories on the shore during the major herring migration.

A. Types of Salting

Since ancient days there have been three basic methods used in the salting of fish; in most countries these methods are distinguished as (1) dry, (2) wet, or (3) mixed.

Dry salting is characterized by the fish being salted with dry crystalline salt. A solution of salt is formed in the water extracted from the fish. The salt, as a result of its hygroscopic ability and osmosis, absorbs the water from the fish and is then dissolved by it. This solution of salt has received in the U.S.S.R. the name of natural "tuzluk" (salt brine). The dry method of salting is used mainly in the barrel salting of herring.

Wet or salt brine type of salting is a process by which the fish is salted in a previously prepared solution of salt. In this method the fish is immediately put into the salt solution, which gives the method the name "wet." It is seldom applied for the salting of herring, and then only in preparing a lightly salted product. The basic deficiency of wet salting is a rapid decrease in the original concentration of salt brine in the preservation process. The adding of salt to one of several places in the vat in order to prevent the decrease in concentration of salt brine does not give the needed effect, because the process of diffusion, which tends to equalize the concentration of salt brine in the vat or barrel, takes place very slowly. This causes unequal fish preservation.

Considering this deficiency of wet salting, T. M. Borisov (U.S.S.R.) in 1939 proposed that salt brine be continuously driven by a pump around the layers of fish. In a special apparatus (concentrator), the concentration of salt brine is brought up to the saturated condition and the salt brine is again used for salting. This method is known as salting in circulating salt brines. It is used in the Soviet Union during the mechanized vat salting of herring in the coastal fisheries (Berezin, 1951; Voskresensky, 1958, 1960).

Mixed salting is a method by which the fish is salted simultaneously with salt and with brine. The fish is rolled in salt, loaded into the vat or barrel, and a certain amount of salt solution is added. In this method, the salt on the surface of the fish prevents the brine from becoming diluted. As it dissolves in the water that comes out of the fish, an additional quantity of salt brine forms. Therefore the salt brine remains saturated and the process of salting begins immediately after the fish comes into contact with the salt brine and salt, without sharp dehydration of the outer layers of fish meat, thereby eliminating the bad points of the two previously described methods.

Salting in connection with chilling of the fish, depending on the quantity of ice used, is divided into warm, chilled, and cold (Voskresensky, 1958).

Warm salting is salting of fish without chilling. In this method, the herring is usually salted during the cool season of the year.

Chilled salting is salting of fish after chilling to a temperature in the range 0–5°C. The chilling fish is intended to stop the autolytic and bacteriological processes in the fish muscle tissue, in such a manner as to preserve the quality of the fish during the preservation in salt. This method is employed in areas with warm climates and, generally, high water temperatures.

Cold salting is a method of salting combined with preliminary freezing of the fish. This prevents the spoiling of the inner layers of the fish flesh. In this way large-sized and fatty fishes can be slowly preserved in salt. The frozen fish is packed in vats and salted by dry or mixed methods. In the initial stage of cold salting, the preserving brine is cold. In effect this method works more rapidly than salting alone. Gradually, depending on the degree of thawing, the salt penetrates into the fish. This method is used in salting very large and fat herring. The Caspian herring "chornospinka" (blackback herring) belongs to this category. This herring reaches on the average 1 kg. in weight with a fat content of 20%.

III. Characteristic Features of Salting

According to rheological definitions the muscle tissue of fish is to be considered a coagulated condensed structure (Rebinder, 1958). Structural and mechanical properties of the flesh tissue together with its hydrophilic disposition greatly influence various stages of the salting process. Basically this can be described as an exchange of matter between brine and salt fish. As a result of osmotic conditions and diffusion of substances in the brine (NaCl, H_2O, etc.) and in the fish (H_2O, nitrogenous substances), this system comes to a practical equilibrium after a certain amount of time.

The actual salting process can be divided into two stages: (1) the salt preservation, as such, and (2) the ripening. This latter stage is especially characteristic for the herring-type fish, particularly those with high fat content.

A. SALT PENETRATION

The salting as such amounts to a process of salt penetration into the fish flesh. This period ends when the salt concentration of the fish tissue becomes equal to the concentration of salt in the surrounding solution.

Movement of the salt molecules from the brine into the fish takes place via a layer of salt solution covering the fish and having a concentration below that of the brine. This layer is formed because water diffuses from the fish, in the beginning of the process, with greater speed than salt molecules from the brine enter into the fish; this layer is a kind of traffic zone in which the flow of matter from the brine into the fish encounters another stream of matter coming out from the fish. As the salting progresses the thickness of this covering layer diminishes as its salt content grows. Diffusion of water from the fish ceases and the salt concentration in this presumptive layer becomes equal to the salt concentration in the brine. The size and nature of this layer exert a great influence upon the salting rate, mostly delaying the motion of salt molecules into the fish. For this reason, the speed of the salting process is usually considerably less in nonstirred brines than during salting with dry salt or in circulating brines (Berezin, 1948; Minder, 1948b; Dragunov and Kosinova, 1950; Berezin, 1951; Voskresensky, 1952, 1953, 1958; Levanidov, 1948, 1954; Nevtonov, 1935).

The salting rate is defined as the amount of salt which has penetrated into the fish during a relatively short period of time. This rate of penetration depends upon the following factors:

(1) Chemical composition, specific surface, and shape of the fish body
(2) Concentration and temperature of the brine
(3) Salting method
(4) Chemical composition of the salt used

The effect of these factors on the velocity of the salting process, either directly or indirectly, is discussed by Turpaev (1926), Tressler (1935), Berezin (1948, 1951), Minder (1948b), Dragunov and Kosinova (1950), Semenov (1952), Levanidov (1948, 1951, 1954), Nevtonov (1935), Voskresensky (1952, 1953, 1958), and Wistreich *et al.* (1959).

When the salt concentration within the cells of the surface layer of the fish muscle tissue reaches its peak, the salt front gradually moves into the inner layers of the muscle tissue. In the preserved zone, where the salt is believed to have accumulated in sufficient quantities, one can see with the unaided eye a change in the tissue color, a kind of darkening. The distribution of salt in the muscle tissue during the salting process has been demonstrated histologically (Yuditskaya, 1950). Salt in the muscle tissue moves further into the tissue in almost a solid front, and the preserved zone has a clearly outlined border which delineates it from the remaining unsalted portion of the muscle tissue.

The extraction of water from the fish takes place under the influence of osmotic diffusion. As a consequence a structural contraction is noted in the muscle tissue. As the salt front penetrates deeper into the fish flesh, the rate of water diffusion is reduced. Finally, the time comes when the movement of water out from the fish ceases entirely. This phenomenon occurs before the end of salt penetration into the fish. The consequence is a minor increase in weight of the fish at the end of the salting period.

After the salt concentration in the cellular fluids of various parts of the fish body reaches 15–20%, the bound (adsorption) water reverts to a free state (Shapiro and Karpov, 1939; Levanidov, 1954). According to later work (Akiba, 1955, 1961; Voskresensky, 1958), the muscle tissue of fish contains 30–35% bound water (per dry substance). As a result of the transformation of water from the bound state to the free state, a reduction in salt concentration takes place in the cellular fluid of the fish meat. This causes additional salt to move from the brine into the fish, resulting in increase in weight of the fish. The water loss is accompanied by a certain shrinkage, not always uniform.

Contraction of the muscle tissue takes place mainly under the influence of electrostatic forces. The terminal ends of the protein molecules determine the structural lattices of the sarcolemma, myofibrils, and myosepta. The electrostatic effect is enhanced through disappearance of the water molecules lying between the protein molecules in the coagulated structure. It is quite conceivable that the water molecules located at adjoining sections of the protein molecules completely vanish. The molecules move closer together. As a consequence, there is a contraction of the fish muscle tissue, resulting in shrinkage. The structural network of the muscle tissue changes and becomes more durable and elastic.

TABLE I

STRUCTURAL AND MECHANICAL CHARACTERISTICS

Stage of preservation	Elasticity	Plasticity	Sulfhydryl groups (mmoles/g. protein)
Fresh[a]	70.7	63.0	71.5
Newly caught fish[a]			
Salted fish (salt content 13.8%); wet salting	93.3	449.0	70.8
Salted fish (salt content 17.8%); dry salting	77.5	10,506.0	26.6

[a] Pre-rigor.

In Table I are shown data characterizing the change in certain structural and mechanical features of the muscle tissue of a sheatfish during salting by dry salt and in brine (Voskresensky, 1958).

The method of salting has a great influence on the structural and mechanical features of the muscle tissue of the fish; considerable changes in shape may result. These findings agree well with observations made in the organoleptic evaluation of these products.

As a result of the loss of liquid, consolidation of the structural lattices takes place. The flesh becomes stiffer and denser. As the salt content in the fish mounts, the rigidity grows. This is observed also in the organoleptic analysis.

During wet salting, a small amount of water is extracted from the muscle tissue. But, other conditions being equal, more salt diffuses into the muscle tissue than during dry salting. This specific peculiarity of wet salting influences to a certain degree the kinetics of deformation.

The process of salting of fish can be subdivided into three stages. In the first stage, the fish is exposed to high osmotic pressure. The active movement of salt into the fish is accompanied by an even more active movement of water from the fish into the surrounding brine. The increase in amount of salt in the tissue is coupled with a corresponding drop in the amount of water. The outer layer of the flesh controls the rate of salt penetration. At this stage a considerable decline occurs in the weight of the fish. No profound chemical changes have as yet taken place. The fish have the odor and taste of a raw fish. The inner layers of the meat, as well as the body organs in the abdominal cavity of the fish, are not fully penetrated by salt.

In the second stage, osmotic pressures still exert influence although on a reduced scale. There is no great difference in the rate of salt moving into the fish, or of the water leaving the fish. Towards the end of this stage, this latter movement ceases and no further decrease in weight is observed.

The salt concentration in the surface layer of the muscle tissue is equalized with that of the surrounding brine. A kind of barrier is formed which limits further movement of the water from either the outer or the inner layers of the meat. A partial redistribution of salt and water takes place within the fish through inner diffusion. Any decrease in amount of salt present in the outer layer of the flesh is immediately compensated by additional salt being picked up from the brine.

In the third stage, minor salt quantities move into the fish. As a consequence the fish weight increases slightly. The salt concentration in the cellular fluid in all parts of the fish body approaches the concentration of the solution outside the fish. Finally they become equalized. The meat of the fish becomes dense, contracted, and has a sharp salty taste; the odor and taste of raw fish are absent.

Three stages can be distinguished in the kinetics of vat salting of prespawning herring of the Okhotsk Sea. The description of the stages in the salting process given so far refers to whole fish, treated dry or by drying and mixing methods. When salting in circulating brine, many specific peculiarities are observed (Minder, 1948a, 1952; Levanidov, 1948, 1951; Fougère, 1952; Kleymenov, 1952; Voskresensky, 1952, 1958; Nevtonov, 1935; Sukrutov, 1959). The quantity of brine formed during the salting depends on the method of salting, content of water, amount of fat in the raw fish, dampness of the salt, and final salt level of the fish. This latter factor has little practical importance. For instance, during dry salting of the Pacific (Sea of Okhotsk) prespawning herring up to a level of 9–16%, the quantity of brine formed reaches 25–27% of the weight of the raw fish (Voskresensky, 1952). Most of the brine is formed during the initial stage of the salting process.

During the final stages of the salting, an increase in weight has been observed by several researchers (Kostomarov, 1862; Levanidov, 1951, 1959; Voskresensky, 1952, 1953, 1958; Minder, 1952, 1954; Semenov and Makarova, 1953; Nevtonov, 1955). This weight increase has been explained in terms of swelling and as an absorption phenomenon.

Swelling induces a movement of water from the brine into the fish (Kleymenov, 1952; Minder, 1952). This has not yet been experimentally proven. The role of bound water, particularly in the second and third stages of the salting, is not clarified. Gradually it is converted to free water. At any rate it can be assumed that myosin and actomyosin in the presence of excess salt are deprived of bound water (Shapiro and Karpov, 1939).

As to further scientific and technical characterization of these various stages, see Voskresensky (1960, with several diagrams on salt penetration).

A second interpretation is based on the absorption hypothesis. In the final stage of the salting, the absorption of water from the brine by the fish tissue takes place at the expense of "complex bodies formed of sodium chloride and protein" (Akiba, 1955). As a result of this, additional salt moves from the brine into the fish because of the disturbed equilibrium in the system: salt solution–fish. According to this hypothesis, there is no satisfactory explanation why "the complex protein bodies" contribute to the absorption of water. It would be more correct to assume that proteins "binding" the sodium chloride (NaCl) reduce the salt concentration in the cellular fluid. This induces additional movement of salt molecules from the brine into the fish.

The ripening of salted fish is the biochemical process that causes the change in chemical and physicochemical characteristics of the fish tissues. These changes are induced by enzymes which break down both proteins and fats. The tissue structure of the muscles and body organs of the fish are also affected. Some of the nitrogenous substances diffuse from the fish into the salt brine. During salting, the exchange of matter in the system is accomplished chiefly by the movement of salt molecules; but during the ripening period nitrogenous substances chiefly of low molecular weight as well as fat pass from the fish into the brine.

The muscle tissue of the salted herring and certain other fish attains a tender consistency and specific pleasant aroma and taste as a result of the enzymic processes.

The rate of ripening of salted fish depends upon (1) the original chemical composition of the raw fish, (2) the salt composition employed, (3) the temperature, (4) the brine composition, and (5) the amount of salt in the fish tissues. Information is very scant as to the actual mechanism whereby these various factors exert their influence. The most conspicuous changes take place in the proteins. These can be measured by the increasing amount of free amino acids and other forms of nonprotein nitrogen in the muscle tissue of the fish, as well as by the increase in quantity of nonprotein nitrogen in the brine. These substances gradually lose their colloidal properties and diffuse from the fish into the brine, where they undergo further changes (Turpaev, 1926, 1940; Kolchev, 1927; Tressler, 1935; Kleymenov and Egorova, 1952; Levieva, 1956a,b; Voskresensky, 1958, 1960; Makarova, 1959a,b).

TABLE II[a]
NITROGEN COMPOSITION OF SALTED CASPIAN HERRING[b]

	Nonfatty fish[c]		Fatty fish[d]	
Days of storage	Nonprotein nitrogen	Amino acid nitrogen	Nonprotein nitrogen	Amino acid nitrogen
0	19.6	5.4	14.7	5.1
203	—	—	23.2	9.1
240	28.4	9.3	—	—

[a] Bochkov and Safronova (1952).
[b] In percent of muscle tissue.
[c] NaCl, 16.6%; fat, 4.8%.
[d] NaCl, 13.1%; fat, 21.8%.

This increase in nonprotein nitrogen of the fish muscle tissue cannot be considered to be a chemical criterion of ripening or be used to evaluate marketability. Table II gives the increase in certain forms of nonprotein nitrogen during long-term storage of salted herring, in less fatty (post-spawning) and fatty specimens.

The nonfatty salted herring differed greatly as to consistency, taste, and odor from normal matured herring, while the fatty specimens possessed all the characteristics typical of the ripened herring. Chemical analysis did not confirm this basic difference. Levieva (1956b) has improved the chemical method for describing the ripening process of salted herring by using the degree of buffering as a supplementary indicator. Reasonably good correlation was obtained between this new indicator and the organoleptic evaluation of the product. The organoleptic method is still safer than any chemical or other method for determining the marketability of salted herring.

Selection of an optimum temperature for the ripening of salted herring depends upon many factors: type of herring, method of dressing, chemical composition of the raw and salted fish, and media (in brine or in the air).

Herring with high fat content, digestive organs filled with feed, and salt content of 8–10% should be kept at temperatures between —2° to 4°C. (28.4° to 39.2°F.). Under these conditions the product ripens slowly and acquires a pleasant taste and odor, with no sign of the sour taste that often appears in lightly salted herring kept at 10°C. (50°F.) and higher. Nevertheless, higher temperatures are sometimes used in order to accelerate the ripening.

Heavily salted herring, on the other hand, ripen slowly and do not acquire the typical taste qualities common in lightly salted herring. Fatty herring after ripening is considerably tastier than less fatty specimens. The oxidative changes in the fat during salting and preservation of the fish are clearly noticeable, but so far there are no satisfactory methods by which it is possible to relate these changes to any of the organoleptic characteristics of the matured fish flesh.

The ripening of salted fish in airtight packs or in tightly packed barrels where the fish are covered with brine yields a better quality product than fish placed in open boxes. In the latter case, an active fat oxidation occurs which results in undesirable products. These may even be toxic and usually have an unpleasant taste and odor (Matsuo, 1959; Fedorov *et al.*, 1957).

These degradation products seem to arise chiefly through oxidative or enzymic reactions from three sources: (1) the muscle tissue, (2) the digestive organs, or (3) microorganisms. The enzymes produced by the microorganisms vary as to type and quantity. All these factors control the ripening process of the salted herring. There are three major hypotheses regarding the ripening mechanisms of salted fish.

1. *Microbiological Theory*

The bacterial flora of the brine in combination with its chemical composition determines the type of changes taking place during ripening of fish in brine (Kiselevich, 1914–1915). According to this hypothesis, the microbes produce the essential active enzymes. These penetrate into the flesh and contribute to its ripening. The microorganisms present originate chiefly on the fish itself and in the salting implements, fixed installations, and salt. According to the vivid expression used by Kiselevich (1914–

1915), the fish, e.g. the herring, "obviously, like the grape, itself carries the particular organisms which play an appropriate role during the ripening of its flesh."

According to this interpretation, the aim of salting is to create the appropriate conditions for the activity of this beneficial microflora as well as to suppress any harmful microflora.

A certain group of microorganisms are active during the ripening of salted fish, according to the findings of Ermol'eva and Buyanovskaya (1934), Ivanova (1940, 1957, 1958), and Ravich-Shcherbo (1948).

This microbial theory attributes significance to both the muscle enzymes and those originating in the gastrointestinal tract. This theory cannot explain in a satisfactory way the ripening of salted herring packed in cans and when the fish is not surrounded with brine.

A considerable number of the Pacific salted herring in the U.S.S.R. are packed in cans, transported, and preserved at 0°C. or lower temperature. Under such conditions (without brine), the ripening process proceeds at approximately the same rate. Oxidative reactions and other spoilage processes contribute to formation of an unpleasant odor.

2. *Autolytic Theory*

Ripening is a result of the activity of enzymes of the muscles or other tissues or of the gastrointestinal tract. The supporters of this interpretation consider the ripening process as an autolytic phenomenon (Sadikov and Shoshin, 1936; Turpaev, 1940). Zamyslov and Sevastyanov (1936) established that cathepsins induce proteolytic hydrolysis in the muscle tissue of the salted herring. This degradation is most active at the isoelectric point. At salt levels in the muscle tissue exceeding 15%, the cathepsin activity is slowed down; but even in a saturated solution these enzymes still appear to be quite active.

The advocates of the autolytic theory attribute to the enzymes of the digestive tract the exclusive role as ripening agents in salt fish. Two reasons are given for their conclusion: (1) the pH optimum is 6–7, i.e., close to the average pH of the brine, (2) the enzyme activity in saturated salt solution decreases to a lesser degree (about 30%) than the activity of the muscle enzymes.

Supporting evidence is the recognized fact that the formation of the so-called "herring bouquet" takes place most quickly and fully during salting of nondressed or only slightly dressed herring with remains of the pyloric caeca, particularly rich in enzymes. In completely dressed herring, the ripening process is considerably slower and the fish does not acquire the typical taste and odor characteristic of a ripened product.

The autolytic theory assigns an insignificant role to the enzymes produced by microorganisms. The weakest part of this interpretation is the identification of the ripening process with the reported autolysis. These processes are in effect not identical. During salt treatment of fish there is not only degradation (of proteins) but also biochemical stabilization when a certain protein, such as globulin, is transformed to a relatively insoluble form (Sadikov and Shoshin, 1936). During the breakdown of raw fish the spoilage in the beginning takes place with the aid of tissue enzymes (see the following subsection), but enzymes produced by microorganisms enter the scene later.

3. *Enzymic Theory*

According to this hypothesis, the ripening of salted fish takes place under the influence of certain enzymes, namely, those contained in the muscle tissue, those in the internal body organs of the fish, and those produced by microorganisms. In addition the changes are influenced by the salting media as well as the biochemical environment in which all the enzymes are acting (Voskresensky, 1958). Tissue enzymes are the most active in the beginning of the ripening process. This period is especially important. Besides breaking down proteins, the enzymes pave the way for microbial activities. It is well established in practice that salted herring acquires considerably more taste and odor when preserved in aged so-called natural brines than when treated in artificial often-renewed brines. This clearly indicates the role of the substrates. Nitrogenous substances in the brine stimulate microbial growth, e.g. of lactic acid producers (Ivanova, 1958), and at salt concentrations up to 20%. The enzymes produced by microorganisms are very important in the end stage of the ripening, and are the main cause of over-ripening of salted fish with subsequent decrease in quality.

There may in the future be a gradual change in the production of salted herring towards the use of smaller containers (cans, barrels, or drums) with simultaneous use of refrigeration. The role of microorganisms and their substrates in the fish will be increasingly investigated. The enzymic theory is at any rate the logical further development of the microbiological and autolytic theories.

IV. Technological Aspects

The food value of the herring-type fish is usually evaluated on the basis of fat content. To a considerable degree this determines also the technological characteristics of the herring as raw material for the manufacture of salted products (Table III).

Whether salting or other methods of preservation are employed it is difficult to use the sexual products of herring to the best advantage.

Table III[a]

Fat and Protein Contents of Herring in Relation to Type and Condition

Type and condition of fish	Content (% of whole)		Chemical Composition (%)										Total fat and protein	Calories (per 100 g. meat)
			Meat		Eggs		Meat			Eggs				
	Meat	Eggs	Fat	Protein	Fat	Protein	Fat	Protein	Total	Fat	Protein	Total		
Pacific herring														
Prespawning	59.5	21.0	5.3	17.8	2.4	30.1	32.0	107.5	139.6	5.1	64.2	69.3	208.9	122.3
Postspawning	71.5	—	1.1	15.8	—	—	7.8	127.2	135.0	—	—	—	135.0	75.0
Fattening	67.5	10.0	18.7	18.0	1.9	30.1	127.1	122.3	249.4	1.9	30.3	32.2	281.6	247.7
Atlantic herring														
Prespawning	61.2	18.3	6.8	20.0	2.4	30.1	41.6	122.4	164.0	3.6	45.2	48.8	212.8	145.2
Fattening	68.1	5.2	21.8	17.4	1.9	30.1	148.5	118.5	267.0	0.9	15.1	16.0	283.0	273.1

[a] Levanidov (1951); Rulev (1958); Makarova (1959).

Furthermore, postspawning herring is of less food value (Levanidov, 1951; Rulev, 1958; Makarova, 1959; Voskresensky, 1958). After spawning, the catch should be limited until the nutritive value of the fish is restored following active feeding.

During development of the milt and roe, the flesh of most herring decreases not only in fat content but obviously also in amino acids, both essential and nonessential, e.g. tryptophan, tyrosine, methionine, arginine, and others. A considerable number of these are actually transferred from the fish flesh into the sexual organs (Petrenko and Karasikova, 1958).

In evaluating the nutritive value of herring flesh in the spawning period, the decrease in fat content is not the only consideration. The change in ratio of essential to nonessential amino acids must also be taken into account. This is of importance to the herring industry. Broad studies are also needed with regard to the regional differences between herring schools.

The following differentiation is at present indicated for herring in the sexual maturity stages II–V according to a six-grade scale rating of degree of sexual maturity:

(1) Extremely active enzymic content: Pacific, North Sea, and Danube herring.

(II) Active enzymic content: Atlantic, Icelandic, and Spitzbergen herring, Caspian blackback herring, White Sea, and Azov-Don herring.

(III) Less active enzymic content: Atlantic-Norwegian herring, Caspian shad (*Clupea caspia*), Volga herring, and menhaden.

These categories need to be investigated further.

A. Salting Technology

1. *Barrel Salting*

The salting of herring in barrels and vats (bins) appears to be practiced throughout the world. The salting of herring in barrels is practiced by all countries which fish in the North Sea and the Atlantic Ocean. During recent years this method has obtained wider use in the Pacific Ocean area and elsewhere.

There are two basic methods of barrel salting: (1) dense packing of the fish without opening the sealed barrel after preservation in salt, (2) salting with less dense packing and subsequently opening the barrels for the final round of the salt treatment.

In the first case, the salting process is not disturbed. The barrel in which the salting takes place is not opened until after the fish has reached a proper stage of ripening. In the second case, the barrels are opened before the herring is sufficiently preserved. The brine is removed and the barrels are refilled with herring of the same day's salting. This latter method is commonly employed by countries catching herring in distant waters.

a. DUTCH METHOD

The Dutch salt the herring on board. Salt preservation is reserved exclusively for the fattened herring of the drift-net catch. Those of the August and September catch are considered the best. When caught before May or after November they are not salted, since the meat contains too little fat for a good quality product.

The usual way of dressing herring is to cut out the gills and thoracic fins with a special knife. Parts of the viscera are also removed ("gekelt"). Another method, less often used, is to remove the gills together with an insignificant part of the viscera. Since a considerable amount of herring is dressed on board when still in fresh condition, partial drainage of blood takes place. After dressing, the fish is mixed with salt and tightly packed in layers in barrels of 100–105-kg. capacity, known as sea barrels ("Zeetonne").

Salt concentration during the treatment of herring is 16–20%. Salt of medium granulation and containing the least possible amount of $CaCl_2$ and $MgCl_2$ is used in order to avoid a "burning" action of the salt and appearance of a bitter taste in the salted fish (Tressler, 1935; Turpaev, 1940; Voskresensky, 1958). When packing the herring in barrels, each layer is pressed by hand without hampering brine penetration into the abdominal cavity of the fish. Each layer of fish is sprinkled with salt. The barrels are filled with fish about 1–2 layers higher than the notches. When the fish have settled and a sufficient amount of brine is formed, the barrels are sealed and stowed away in the hold.

After arrival in port, the barrels are unloaded and stacked on shore in special sheds or under a roof in stacks 2–3 barrels high. They are held there for a 3–4-month period until the fish are fully ripened. Then the herring are transferred to tubs for washing and removal of brine. Subsequently they are graded for size and quality, packed into special marketing barrels of small size, and covered with brine from the sea barrels for later shipment to the retail market.

After regular maintenance and cleaning of the empty barrels, they are again used at sea for the salting of new lots of freshly caught herring.

b. ICELANDIC METHOD

As the catch of herring takes place close to the coast, salting is conducted on land. The fish are usually beheaded; thoracic fins are removed; the viscera are partially eliminated together with the head. After washing in water and draining, the fish is rolled in salt and packed in barrels. The salt content is 22–23%. For salting, a mixture of medium and large granulated salt is used. The salting is done with great care, directly in commercial barrels, so there should be no need for additional packing of the salted fish. For this purpose, a plywood ring 20–25 cm. wide is put on the barrel; the diameter of the ring corresponds to the diameter of the upper part of the barrel. During the salting, packing takes place up to the level of the top of the ring.

Approximately one day after salting when the fish have completed the necessary settling, they are compressed (usually manually). Then barrels are filled with additional brine if needed, and sealed.

During further preservation the settling continues but no refilling of the barrels with salted fish is done, since the Icelanders maintain that any opening of the barrels impairs the quality of the herring. Ripening requires a long time because of the cool climate.

c. SCOTCH METHOD

The salting is done on shore. For a detailed description of this method, see Stamer (1931) and Anderson and Pedersen (1952). The essentials of this method on the basis of these studies are as follows. Herring of large and medium size are dressed with removal of thoracic fins and intestines. The fish are not washed; after mixing with salt, they are packed in layers in barrels. Each layer is sprinkled with salt. The amount of salt added increases towards the central section of the barrel. When full the barrels are sealed. For equal salt distribution the barrels are periodically rolled around; this treatment lasts for 10–16 days. Then the barrels are refilled with herring of the same day's salting. Before sealing, the barrels are filled with brine.

The salted herring are not always completely ripened at the processing plant, but are quite often sent to the consumer and allowed to finish ripening en route. The Scotch method of salting is used in Newfoundland, Alaska, and British Columbia with minor differences.

From the middle of May to the beginning of June, young herring just developing sexual organs appear near the coasts of Ireland and Scotland. The product prepared from this herring is called mattie-full and mattie (virgin herring). In this case, only small amounts of salt are employed; after filling the barrel with herring the brine is added. The salted herring is stored for ripening under chilled conditions. The flesh of herring preserved in this way is of a tender juicy consistency. The Scottish herring product is in general better than those prepared from German and Dutch herring (Stamer, 1931; Pielenz and Kramer, 1958).

d. Russian Method

This method is characterized by (1) salting of the whole herring, (2) use of comparatively small amounts of salt, (3) packing in layers, and (4) ripening in the natural salt brine at low temperature (about 0°C.). In developing long-range ocean fisheries in both the Atlantic and Pacific Oceans, this rather complete technology had to be simplified in order to speed up production and to facilitate the labor of workers during the strong pitching of fishing vessels on the high sea.

Barrel salting of ocean herring on the high sea is in the majority of cases at the present time conducted in the following way. The whole fish with viscera is thoroughly mixed with salt on the deck of the fishing boat. The barrels are filled with herring without packing in layers, up to about 5–8 mm. above the notch groove. A layer of salt is placed on the bottom of the barrel. The amount of salt added should be adequate to give a final salt concentration in the fish of 16–20%. Three-fourths of the salt is applied directly to the skin by rolling the fish in the salt. The rest is used for sprinkling the fish when in the barrel. The barrels are sealed and packed in the hold within less than 6 hours.

The dry barrel salting of herring on board a ship at sea often leads to unequal distribution of salt and hence less uniform preservation. It is difficult during the salting, without packing in layers, to distribute the salt and fish equally in the barrel. Rulev (1958), aware of this obvious deficiency of dry salting, suggested a mixed salting of herring.

The actual work is now performed in the following way. Four to five liters of saturated solution are poured over the herring, mixed with salt, and placed in the barrels without layer packing. The barrel is overfilled with herring, as much as is feasible. Above the upper notch groove, a layer of about 4 kg. salt is poured onto the top layer of fish. The quantity of salt needed for 100 kg. herring, except for the preparation of 5 liters of a strong salt brine, amounts to:

(a) From October 15 to April 15—*18 kg.*
(b) From May 15 to September 15—*22 kg.*
(c) From September 15 to October 15—*21 kg.*

After filling the barrels with fish and salt, they are held for not more than 1 hour to allow settling of the fish and then sealed.

Due to this shrinkage of the fish, the barrels are opened and filled anew with herring from barrels of the same day's batch. Then comes sealing and flooding with brine. When the transport vessels return to port, the fish are transferred to new empty barrels. These are closed after being flooded with brine saved from the emptied barrels. After being held for some time to allow full ripening, the salted herring is ready for sale to the consumer.

During recent years in the Soviet Union, the salted North Sea and Atlantic fat herring have been packed in rather small cans of 3–5 kg. The herring are salted directly in the can, but with reduced amounts of salt and addition of sugar and preservatives. Later the cans are tightly sealed and placed in the hold of the ship at a constant temperature of about 0°C. They are held at this temperature to allow the fish to ripen, then sent to market. The salted herring, especially from the North Sea, prepared in this manner has a reputation for good taste and tender consistency.

e. NORWEGIAN METHOD

Most of the raw material for the Norwegian pack is caught near the shores of Norway, and salted on land. Quality-wise, shoal herring is considered best. It is caught from July to September in the high sea. In the summer period this herring contains up to 25% fat. Since the shoal herring is caught far from shore, the salting is conducted on board the fishing vessels.

The procedure employed differs little from the Dutch method. Salting is done in barrels of about 100-kg. capacity. The final salt concentration is 18–20%. The herring is not dressed prior to salting.

Upon arrival of the ship in port the sea barrels are emptied. The herring is sorted according to size. The fish is rinsed, weighed, and packed in clean barrels in layers with a sprinkling of salt on each layer. The additional salt amounts to 4–6% of the weight of the fish. When filled with herring, the barrels are flooded with a mixture of natural and artificial brine, and sealed. Afterwards additional flooding with brine through openings in the barrel is done. After keeping for a short time, the herring is sent to market.

The herring caught in fjords or offshore bases are salted only on land. Such herring are kept alive for some time after the catch in fish storage ponds, in net gardens, or in the salting plants. The fish are dressed with removal of thoracic fins by special scissors, and sorted according to length. Each fish size is salted in separate barrels. Before salting, the fish are not washed or mixed with salt. They are packed in layers with sprinkling of each layer with salt. After 8–10 days the barrels are opened and filled with herring of the same day's salting, size, and kind. The barrel is finally sealed and marked. If there is too little brine in the barrel, brine is added through special openings.

2. *Vat Salting*

Vat salting of herring is used in the Soviet Union, Japan, Norway, North Korea, and other countries, and is conducted in the following manner. The herring are delivered to the factory, graded for weight and quality, and washed. In cases where the fish are carried by hydroconveyors, additional washing is not required. A layer of salt 0.5–1.0 cm. thick is spread on the bottom of the vat. A saturated brine is poured in to fill the vat up to 15–20 cm. The herring, previously rubbed with salt, are loaded into the vat in uniform layers. Each layer of fish is covered with salt. During the warm period of the year, finely granulated ice is placed on top of each layer. In order to compensate for the water added in this way, the amount of salt is increased. The salt fluctuates in the range 24–36%, depending upon the amount of ice used. After filling the vat, the upper layer of herring is covered with clean bast mats to avoid contamination of the upper layers. After 1 day, the brine formed usually fills the vat completely. The bast mats are removed and lattices made of smooth wooden strips are placed on top of the fish. A weight is put on the lattice in order to submerge the fish.

For uniform preservation of the fish, the brine is transferred from the lower parts of the vat to the upper parts after approximately 5 days. Sometimes the fish stick together in this operation and have to be loosened. With chilled salting the entire process takes 14–20 days, while salting at room temperatures requires 10–14 days (Voskresensky, 1953, 1958).

Each layer of fish is packed at a right angle to the layer below. After filling the barrel, the fish are slightly firmed by special presses and more fish are added if necessary. Then the barrel is sealed and salt solution poured into it. The packing of salted herring in the U.S.S.R. has been largely mechanized in recent years with the use of special vibrators.

In Japan combined salting is used, the essence of which is as follows. The fish are first salted in the vat with more salt added subsequently. The total amount of salt used is 15%. The vat is loaded approximately 30–50 cm. above its rim. The fish on top are covered with bast mats soaked in salt brine. Salt brine is formed in about a day and the fish shrink and are submerged. The fish are salt-treated in the vats for 3–7 days. Then they are removed from the vat, densely packed in barrels, and flooded with saturated brine, 80% of the volume. The barrels are sealed and filled with brine and the salting continues for another 6–7 days. The openings in the barrels are closed with wooden corks. The barrels are kept in cool dark rooms. When packed in cans, the fish are sprinkled with salt in an amount not less than one-tenth the weight of the fish.

a. SOUTHERN HERRING

Vat salting of southern herring is largely practiced in the Volga-Caspian basin (U.S.S.R). The technique of salting these small-sized herring is as follows. The fish are salted in an undressed condition. Brine is poured in the bottom of the vat in a layer of not more than 25 cm. Then the first batch of fish is placed in a layer not more than 25 cm. deep. Each following layer of fish is covered with salt. The top layer of fish is covered with salt. Loading of the vat is done in batches of 50–100 kg.

Each layer of fish is covered with salt; in the case of chilled salting, salt is also added to the finely granulated ice.

This method has been termed a salting in bulk or one of similar pattern. Salt is used in room temperature salting to 26% of the weight of herring, during chilled salting to 35–40%. In general the salt is not distributed uniformly as the top layers frequently take up 1.5–2 times more than the lower layers. After 1–2 days when a sufficient amount of brine has been formed, the fish are covered with bast mats on which a layer of salt 10–15 cm. thick is sprinkled. Quality and strength of the brines are periodically checked during the salting.

Large herring, more than 35 cm. in length, are salted with layer packing only. The fish are first chilled with ice-salt mixture. On the bottom of the vat there is placed a layer of salt, then a layer of fish with ventral parts upward. This is covered with a layer of salt and a layer of fish, etc. As the vat is filled, the amount of salt per fish is increased; the upper layer of fish is covered with bast mats on which salt is poured. The vat, filled with fish, is covered with wooden lattices. The use of salt during cold salting of herring amounts to 35–40% and with ice to 70–80%. The period of salting is not less than 25 days (Berezin, 1948; Voskresensky, 1958).

The salted herring are unloaded from the vat, washed in chilled brine, sorted according to size and quality, and finally packed in barrels of 100–150-kg. capacity, ready for shipping to the market.

b. Atlantic Herring

Winter and spring Atlantic herring are salted in large deep vats with a capacity of 20 metric tons of fish. The salting is done without layer packing; the salting techniques do not differ from those for Pacific herring; the fish are not chilled in the summer. The salted herring are dressed and then packed into barrels. After sealing the barrel, saturated salt solution is poured into it. The salting continues for a minimum of 15 days (see further Anderson and Pedersen, 1951).

In New England and Canada, the herring are washed in brine immediately after capture. Then the fish is cut along the center of the ventral part to the anal opening and the viscera are removed. Washed fish may be kept in weak brine for 2–3 hours. After drainage of the brine, the internal part of the fish is rubbed with salt. Its final salt concentration is 35%. After 7 days, the fish are taken from the vat and placed in barrels with the dorsal part down and salt is sprinkled between the layers.

3. *Salted Herring Quality*

The quality of salted herring from different countries is very difficult to compare, since each country has a certain type of high quality preparation. The following such products are encountered in the U.S.S.R.: (1) fat Pacific herring (caught on the eastern shores of Kamchatka), (2) Danube and (3) Atlantic fall herring (large herring from the Spitzbergen and Arctic catches) (4) Dutch (fat herring) and especially (5) Scottish (mattie-full) herring are of exceptionally good quality. (6) Icelandic and (7) Faeroe herring are large and have a high fat content. Beheading reduces somewhat the market value of the fish. Singled out as superior products are certain categories of Norwegian salted herring: (1) small immature herring of the fall catch (fetsild) and (2) winter herring (storsild), which sell readily in the fish markets largely because of their fat content and tender consistency. The criteria for good quality in salted herring are determined by type and size of the fish, fat content, and salt percentage, as well as consistency of the flesh. Odor is given consideration in the U.S.S.R. as an additional indicator of the degree of ripening. Furthermore, each country has its own regulations as well as special standards with reference to rules for the marketing of salted herring.

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CHAPTER 4

Salted Cod

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I. Introduction

Dried and salted cod has a long and intriguing history. It has played a role in human history out of all proportion to its quantity. It constituted a first-rate protein concentrate addition readily marketable and easy to handle without elaborate packaging. This history is reviewed in detail in Volume II, Chapter 1.

A prerequisite for the manufacture of this item is naturally rich fishing grounds. Some of the richest in the world were discovered early in human history and are to this day the scene of intense fishery by a growing number of nations. A second prerequisite is salt. This comes from various sources and will be briefly reviewed.

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[1] Deceased November 3, 1959.

II. Salt and Its Impurities

It is impossible to tell which method of food preservation was first used by primitive man. Drying, smoking, and salting are very ancient. In moist climates at least, salting may have been the first method.

A. Properties

Common salt is more or less impure sodium chloride (NaCl). It is a white lustrous solid that generally crystallizes into cubes. In water solution it has a bitter brackish taste and is neutral to indicators. Pure sodium chloride is slightly hygroscopic, taking up about 0.5% of the moisture from the air at ordinary room temperature. It melts at 1421°F. (772°C.) and vaporizes rapidly at white heat.

Sodium chloride in concentrated solution possesses antiseptic properties since it extracts water; salt is therefore often used in the preservation of meat, fish, and other food products. In addition to seasoning the food and preserving it, salt is used in large quantities for curing of hides, making of brines for use in refrigeration and ice factories, making of dyes, and preparation of sodium and chlorine (Tressler and Lemon, 1951).

B. Deposits

Salt deposits originate from the soil, from which it is constantly leached by rain. This led to accumulation of NaCl in the oceans, which varies from 2.7% (w/v) in the open sea to 3.0% in the Mediterranean Sea and in some inland lakes like the Dead Sea to 7.9%. The Great Salt Lake (United States) is so saturated that it shrinks in years of inadequate rainfall. Changes in climate caused formation of the huge underground deposits which are often found at appreciable distances from the coast.

C. Solar Salt

Salt is extracted from sea water in regions where climatic conditions are favorable for evaporation, i.e. southern France, United States, the Mediterranean, and some tropical countries such as the northern shores of the Indian Ocean. The solution is pumped into large shallow beds, where most of the less soluble impurities like silicates, calcium sulfate, and calcium carbonate precipitate during concentration of the brine. After a few repetitions of this process, which requires a total of 40 days, about 60 kg. salt of 95–97% purity is obtained per square meter.

D. Mined Salt

Subterranean deposits sometimes occur in solution (Lüneburg, Reichenhall, Germany); this is pumped up and concentrated in open pans or allowed to run over large walls built of thorny bush, which hold back the more insoluble impurities while the water evaporates. If these deposits are dry, mining is carried out with small charges of explosives.

E. Salt Impurities and Their Effect on Fish

The solar and mined salt on the market is not always entirely pure. Both can be purified to 100% NaCl, but at a price the industrial consumer may not be prepared to pay.

The over-all average analysis of salts of various origin, used by the fishing industry in Eastern Canada, is: NaCl 97.7, water 2.4, calcium sulfate (gypsum) 1.08, magnesium chloride, 0.30, calcium chloride 0.24, magnesium sulfate 0.17, insoluble material 0.40 (Beatty and Fougère, 1957). Yellow and brown discoloration of the salt indicates the presence of iron in more than traces. Such salt should not be used for fish, since even 30 p.p.m. iron and 0.2–0.4 p.p.m. copper catalyze the formation of a brown or yellow stain in salted fish (Dyer and Gunnarsson, 1954; Arnesen, 1954). However, curing with salt containing 1.5% calcium chloride prevents the yellow coloration which occurs occasionally in fall cured cod, and a dip in 0.5% calcium chloride solution removes it (Legendre, 1954). Other impurities invisible to the naked eye are equally important because they affect adversely:

(*a*) Penetration of salt into the muscle.
(*b*) Color and texture of the final product.
(*c*) Taste and flavor of the final product.

The penetration of salt may be retarded two full days by addition of 4.7% magnesium chloride. This disturbing effect is most serious because in the early stages of salting the fish is still very perishable, the amount of salt which penetrates into the muscle being inadequate to inhibit bacterial action.

Pure sodium chloride produces a flexible salt fish of light amber color which after desalting and cooking is quite similar to the original product. One percent of magnesium and calcium salts produces a noticeable change in appearance of dried salt cod; two percent gives a product which the trade accepts, not so much for its ideal character as the fact that the salt commonly used contains this amount of impurities (see analysis above). Five percent renders the product chalky white, stiff, brittle, and of strong acrid flavor (Boury, 1932; Carter, 1932; Reay, 1936); in addition it favors the yellowing of salted fish. The most satisfactory composition for impurities has been determined as 0.15–0.30% Ca and 0.05–0.15 Mg, mostly as sulfates, with a molecular Ca:Mg ratio of 1.5 to 3.0 (Soudan, 1955). Another extensive study describes a technique for determining salt penetration into the fish, using blocks of muscle 4–5 cm. in diameter which are salted dry or in brine (Charro, 1953).

Fine salt has the advantage of dissolving rapidly; however, it is so hygroscopic that it cakes in moist weather. When in the latter form it is difficult to obtain a uniformly salted fish. Moreover the salted fish may be too closely packed when fine salt is used; this counteracts the formation and uniform distribution of the pickle.

Coarse salt is less soluble, since on a weight to weight basis it offers a smaller surface for the process of dissolving. Consequently salt penetration is retarded. As stated above, this is dangerous because the fresh fish is very susceptible to bacterial destruction in the early stage of salting; the bacteria of the fresh fish are killed or inhibited only when the salt content of the muscle has reached 5–6%. The fishing industry terms the penetration of salt "striking through." Fresh fish, i.e., the product before salting, is called "green." Beatty and Fougère (1957) report the most suitable salt to consist of a mixture of equal volumes of fine salt and coarse salt, the latter containing particles up to ¼ inch in diameter. Depending upon the time required for the salt to strike through, the salters distinguish between strong and weak salts. This erroneous concept arose from the fact that salting is not done on an accurate weight to weight basis. Each fish is salted individually by hand, that means by volume, so that the so-called difference between strong and weak salts is in fact only the difference in specific weight of fine and coarse salt.

III. Processing of Salted Cod

A. Treatment on Board Ship

Cod is caught by trawl line and hand line, also by otter trawl and floating traps. The use of the latter two may cause waste, since so much fish is caught at one time that deterioration may set in before the catch is safe-guarded or processed. Depending upon the distance between fishing ground and home port, the raw material is either salted on board, as on the Pacific Coast (Lucas, 1951), and cleaned, washed, and kept on ice until landed, or is kept whole for processing ashore. In the latter case provisions should be made for protection from sunshine, for ventilation, and for rinsing with sea water. It must be emphasized that the care of the raw material at sea is at least as important as a proper salting procedure (Beatty and Fougère, 1957). Pews or pitchforks are to be condemned in the handling of the raw fish (Jarvis, 1950). Hoists or conveyors have gradually come in to common use; otherwise bacteria, originating from slime and excreta, enter the flesh and find a particularly fertile breeding ground where the skin has been pierced or bruised. This is confirmed by Ludorff and Kreuzer (1956), who emphasize that the hook or fork, if used at all, should be used only at the heads. The same authors warn against stepping on fish or throwing it.

Warm weather or inadequate precautions may cause:

(1) Softening of the flesh.

(2) Development of cracks ("putty" fish).

(3) Enzymic decomposition starting at the intestines (belly burn of herring and mackerel, liver stains of cod, etc.).

The softening is due largely to proteolysis. In this condition the flesh of the split fish tends to flake apart, appears mushy, and gives a rough surface after drying.

The cracks occurring in "putty fish" expose the fish flesh to bacterial attack in the same way as pitchfork damage. Subsequent salting does not help, because the cracks are closed again by the pressure to which the fish are exposed in the tanks; the two days, which are the minimum for the salt to penetrate, are adequate for bacteria to multiply inside the damaged part. Inadequate salting may be another reason for putty fish. In this case the surfaces have been pressed together so that bacterial action is again faster than the salt penetration.

Icing on board appears to be the best method of preventing the three types of damage mentioned, if the fish cannot be processed aboard. However, Jarvis (1950) states expressly that the best quality product is obtained when the fish is taken alive from the gear and bled immediately, since blood is a rich source of enzymes. The same author recommends a time limit of 3–4 hours between catching and salting. If this is impossible the fish should be bled, washed, and iced, provided these procedures are carried out thoroughly. Otherwise they may do more harm than good, because small amounts of blood or bits of viscera are excellent breeding grounds for decomposing bacteria, and because contamination from the slime is difficult to prevent. The washing procedure is essential. After 9 days of salting, perfectly cleaned and washed fish were in perfect condition in spite of a high temperature (80°F.) (Tressler, 1920).

B. Dressing

The precautions mentioned are excellent in theory but numerous difficulties arise in practice. It is self-evident that the water used for washing should be clean. Offal thrown overboard may severely contaminate the sea water. Bacterial counts of the water of the fishing grounds have been found to be 8 times higher than that of surrounding waters and 18 times higher after a catch has been handled.

The quality of the caught fish is improved primarily by cooling and holding in refrigeration holds or by using preservative chemicals (see further Chapter 17, Volume I).

The cod is usually stored on horizontally arranged wooden boards. Each layer of fish is only 2 ft. high in order to prevent damage by crushing. Special boxes have been constructed, either from wood with a plastic covering or from light metal, which are easy to stack and to handle. Liability of damage by the sharp edges of the ice and by the drip of melting ice is considerably reduced, and the fish are delivered in these boxes to the processor. Several types of such boxes are commercially available in the United States, Canada, and Europe.

C. SALTING

Depending upon climatic and geographical conditions, various methods for salting and drying have been developed. Kench salting, pickle salting, and brine salting are distinguished and also light and heavy salted fish. The so-called "fall cure" has salt and water contents between those of the latter two commodities.

1. *Kench Salting*

In this method the split salted fish are piled into stacks to a height of 4 feet, layers of fish and salt alternating. More salt is put on thick fish and thick parts of normal-sized fish than on thin fish and thin parts of normal ones. The pickle is allowed to drain off, for which special provisions are made; one of these is the arrangement of the pile, which is higher at the center than at the sides. In the lower layer the fish are placed with the flesh side up, the top layer is spread skin up. In spite of this precaution bacterial contamination, manifested as slime, occurs easily with light salted cod, because the total surface exposed to the air is larger than in pickle or brine salting. The most critical factor is of course the temperature; at or above 15°C. (60°F.) spoilage is difficult to avoid. Limitation of space, as for instance on board schooners, is the only reason that this method is still used. This applies to vessels that catch cod at banks far from the home port, e.g., the French, Norwegian, and Scotch boats, that fish at Newfoundland, Lofoten, and Iceland, respectively.

Contrary to pickle salting, products obtained by kench salting contain an adhering salt layer, which must be removed before drying. The old method, still partially in use, does this with hand brushes; however, machines have been developed for this purpose.

2. *Pickle Salting*

In this method dry salt is applied to the flesh side of the fish, as in kench salting. However, the fish are put in cement tanks of 14 × 4 × 4 ft. or in sawed-off wooden barrels 4 ft. in diameter and 4 ft. high. As was stated, salt dissolves in the water at the surface of the fish and forms a strong brine. In pickle salting the fish remain in the brine, and due to the tendency to approach an equilibrium, salt travels into the fish muscle and water is extracted. Coagulation of the fish protein sets in when the salt concentration in the muscle has reached 10%. Light salted fish is prepared by adding salt only at the center, where the backbone has been removed.

3. *Brine Salting*

In pickle[2] salting, the water of the brine derives from the fish. It is also possible, however, to salt fish by immersion in a solution of salt and tap water. This procedure is not used for salted cod to be dried, because the thinner parts may be oversalted; this is manifested after drying by an unacceptable rough appearance of the surface. The method is, however, applied to alewife and herring. These fish are cleaned and put in large wooden containers partly filled with strong brine. After being struck through they are tightly repacked in wooden barrels, the air space of which is filled with new brine. Dry salt is added to the top layer. These salted fish are not dried but are sold in brine to the retailer. Part of the herring catch is also salted before smoking (see Chapter 3, this volume). Brine-packed cod is manufactured on a limited scale in Maine (U.S.).

4. *Water-Horsing*

If salted fish is dried immediately after completion of the salting procedure, a rough surface is produced. Consequently, the salted fish is washed and kept in piles, which is called water-horsing. In this operation, the pressure of the pile promotes the draining off of the brine and causes the final product to be thinner. As a result the drying rate is increased. In addition, the surface is smoothed.

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[2] The expressions brine and pickle appear to be used interchangeably. This was permissible as long as brine salting of cod played a minor role. Considering, however, that the industry is to be mechanized by developing a brine salting procedure in which the complications mentioned are avoided, a clear-cut differentiation between the two terms would be advisable. It is proposed to define pickle as the fluid obtained by the dry salting of cod, and to reserve the term brine for the solution of salt in water in which the fish is immersed.

5. *Special Procedures*

a. GASPÉ CURE

In the Canadian provinces located near the Baie des Chaleurs, namely, the Gaspé Peninsula and northern New Brunswick, climatic conditions are so favorable that a light salted cod, containing only 14–18% salt in the dry finished product, can be prepared. Light northwesterly winds prevail and temperature and relative humidity are usually below 75°F. and 80%, respectively. They may be higher during July and August, which may lead to products of lower quality. More salt is used during these months. Italy, Spain, and Portugal insist nowaday on first-rate products of this type and are prepared to pay for them.

The precautions mentioned are important for any type of salted fish product. For Gaspé cure, which is salted with only 8–10 lb. per 100 lb. fresh (split) fish, they are imperative. In this respect, it is of interest that the salt content of 4–6% before drying is quite ideal for slime-forming bacteria. Therefore fish submitted to Gaspé curing should be dried immediately after salting. If this is impossible it may be stored for a maximum of 6–8 days, provided the temperature is maintained between —1°C. and 8°C. (30° and 46°F.).

b. FALL CURE

The salt content of this commodity is between that of Gaspé cure and heavy salted fish. As the name implies, this type of salted fish is manufactured late in the season.

The process is identical to that of manufacturing Gaspé cure, except that more salt is used, 12–15 kg. per 100 kg. split fish. The reason for this is that consumers of this product demand a whiter appearance than that of Gaspé cure, and prefer the texture of the product, which is not as hard as that of Gaspé cure. It contains 45% water after drying against 36–38% for Gaspé cure, which is permissible since the product is sold mainly to the northern parts of the United States, so that spoilage during transport is not very probable. The product is manufactured in New Brunswick and to some extent also on the Gaspé coast.

c. HEAVY SALTED COD

It has been explained that salt has a dehydrating effect; that means the original 80% water of fish is reduced by different methods of curing to values of 55–74%. In heavy salted cod this residual water is completely saturated with salt. Saturated brine contains 36 lb. salt per 100 lb. water. Consequently the theoretical amount of salt required would be $36 \times 0.8 = 29$ lb. per 100 lb. split fish, but in practice 35 lb., sometimes even 40 lb., are used. Many variations in salt content and manipulative treatment exist in different countries. Penetration of salt depends upon its concentration in the pickle and upon the muscle thickness (Fig. 1). Temperature appears to have little effect on salt uptake but, as in the case of Gaspé cure, salting should be carried out at temperatures below 65°F.; otherwise a soft product may be obtained. During the first few days, pickle formation proceeds at a rapid pace; thereafter it slows down. Consequently the upper layer of the pickle may be unsaturated. This is avoided by covering the top layer of fish with a small excess of salt.

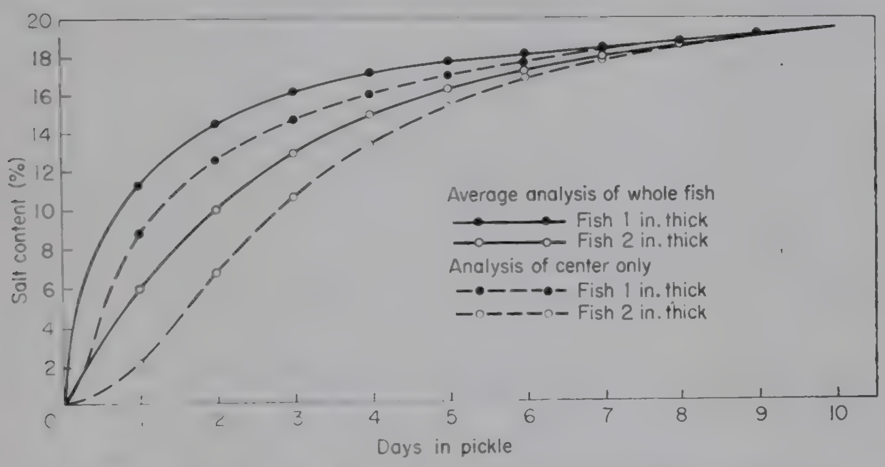


FIG. 1. Penetration of salt in cod muscle. (Thickness of fish represented by upper curves: 1 in.; lower: 2 in.) From Beatty and Fougère, 1957.

IV. Chemical Features

Extensive studies have been made on the denaturation and breakdown of fish protein into polypeptides and amino acids, and on the changes occurring in fatty substances during salting of cod and other fish.

A. PROTEIN DENATURATION

The expression denaturation implies that under the influence of increased temperature or salt the structural arrangement of the protein molecule has been changed, whereby the protein is rendered insoluble. A similar process occurs in cod muscle during salting where, as shown in Fig. 2, the soluble protein is gradually reduced until, after 18 days, it reaches a constant level. This study confirms the practical experience of fishermen, who keep heavy salted fish for at least 18 days but usually 30 days in pickle, because when salted for shorter periods the skin cannot be torn from the flesh; this means the latter has not acquired the suitable denatured consistency (Fougère, 1952).

B. Enzymic Breakdown of Protein

Endo- and exopeptidases are differently affected by the gradual increase in salt concentration that takes place during the drying process. Determinations of the α-NH_2 group in the total free amino acids, of α-NH_2 in the proteins and peptides, and of TMA (trimethylamine) values have been made on a number of commercial samples of the three different cures. In spite of variations, a definite trend is discernible. Free amino acids and TMA values of heavy salt cod are lower than those of Gaspé cure. This may be correlated with the difference in bacterial counts of the brines of these two types of salt fish, those of light salted fish being much higher than those of heavy salted fish (Bilinski, 1958, unpublished).

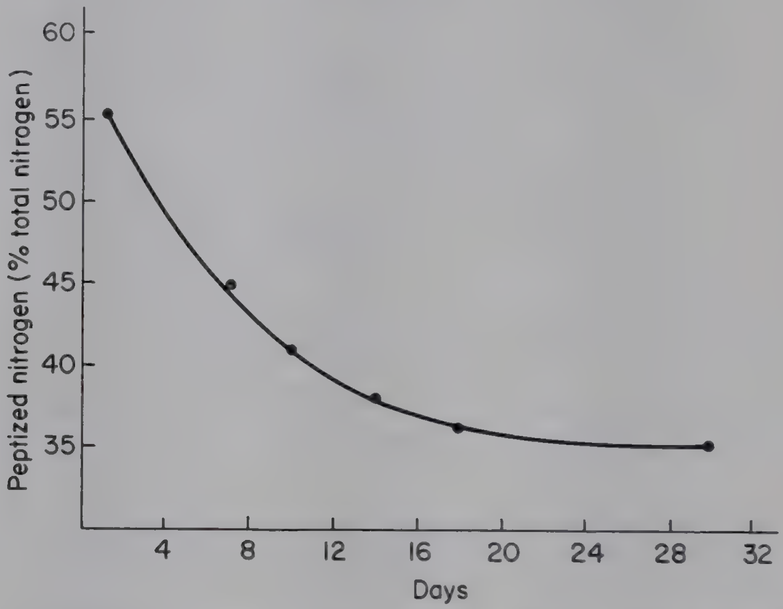
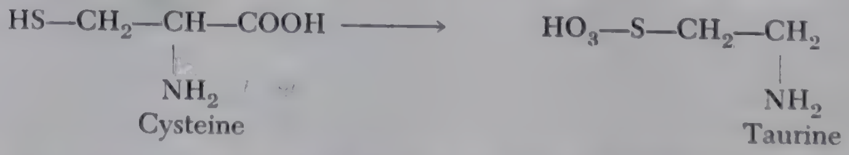


Fig. 2. Reduction of soluble protein in fish muscle during the salting of cod. From Beatty and Fougère, 1957.

C. Pickle Constituents

Apart from salt, the brine of cod contains about 0.5% (w/v) of a soluble protein which can be precipitated by boiling or trichloroacetic acid, and an appreciable amount of free amino acids, among them taurine which originates from cysteine according to the reaction:



$$\underset{\text{Cysteine}}{\mathrm{HS{-}CH_2{-}\underset{\substack{|\\ NH_2}}{CH}{-}COOH}} \longrightarrow \underset{\text{Taurine}}{\mathrm{HO_3{-}S{-}CH_2{-}\underset{\substack{|\\ NH_2}}{CH_2}}}$$

The high amount of taurine found in pickle corresponds roughly to the amount present in fish muscle (Jones, 1954; van Klaveren, 1958, unpublished) and may be assumed to have been leached out during the salting procedure.

Another outstanding feature is the high content of alanine in pickle. Also the pickle has a golden yellow color and in the initial stage a greenish fluorescence in ultraviolet light, which changes to blue rapidly on boiling and exposure to sunlight, slowly on standing at room temperature. The yellow pigments can be separated from the blue fluorescent substances by chromatographic methods. Both are due to the well-known Maillard reaction, in which free amino acids react with ribose to for Schiff base compounds and a great number of decomposition products. It must be concluded that the ribose split off in salting originates enzymically from the nucleotides in much the same way that Tarr (1955) has shown for raw fish.

Taurine appears to be one of the most important sources of Maillard compounds in pickle (van Klaveren, 1957–1958, unpublished). The yellow spots sometimes observed on salt fish also show blue fluorescence under ultraviolet radiation and are probably related if not identical to the above, because they are found in the vicinity of disodium hydrogen phosphate crystals which have been formed on the surface (Section V, E).

Cod flesh is comparatively lean; it contains only 0.7% (wet basis) or 3.5% (dry basis) fatty material. The latter is hyrolyzed by fat-splitting enzymes, the lipases. The rate of hydrolysis has been determined by analyzing the phospholipid and glyceride fractions of the total lipids during various stages of salting and drying. The rate of hydrolysis is different for light and heavy salted cod, although both cures finally produce approximately the same amount of free fatty acids, namely, half of the total. In light salted fish the free fatty acid content increases gradually at each step of the process; in heavy salted cod it increases rapidly during the first 10 days of salting and levels off thereafter.

Other experiments, in which phospholipids and free fatty acids of heavy salted cod were analyzed at smaller time intervals, prove that the liberation of the latter is accompanied by a proportional decrease of the former. This phenomenon is most pronounced from the 7th to 10th day of salting, when the salt uptake of the cod muscle increases only from 15.5 to 17.1%. No further hydrolysis takes place thereafter.

These results show that salt does not inhibit those enzymes responsible for liberation of free fatty acids of the greater part of the phospholipid group, but that a salt concentration exceeding 17% interferes with the hydrolysis of the remainder, which constitute 22% of the total (Cardin *et al.*, 1957).

A pronounced increase in iodine values of the lipid fraction takes place during the initial stage of the manufacturing process.

During the preparation of the Gaspé cure, 76.7% of the fatty acids are liberated from the phospholipids. The C_{16} group, saturated and unsaturated, is nearly completely split off, 85 and 90%, respectively. This group constitutes, however, only a small proportion of the total fatty acids. About 57% of all liberated fatty acids belong to the C_{20} and C_{22} groups, which are highly unsaturated. The unsaturated acids ranging from C_{16} to C_{24} are liberated to a very large extent, irrespective of their chain length. The proportion of saturated acids liberated decreases as the chain length increases.

The unsaturated fatty acids are liable to oxidative decomposition at the double bonds; the resulting substances, mostly ketones and aldehydes, appear to be largely responsible for the flavor, possibly also for the taste of salted cod. Recent observations indicate that about 90% of the specific salt cod flavor is contained in the volatile reducing substances (Cardin, 1958, unpublished).

V. Spoilage

A. Introduction

In spite of the preservative action of salt, the industry has to deal with a number of spoilage problems. The inhibitory action of salt on microorganisms depends largely upon its concentration. Moreover, microorganisms have outstanding adaptability, so that conditions lethal to one group may be ideal for another. For instance, fresh-fish spoilage bacteria are even stimulated at concentrations of 1% NaCl, and are quite active up to 6–8% salt. At this percentage they die. Another group, the slime-forming bacteria, thrive on salt concentrations of 6–12%. Even increasing the salt over this tolerance limit does not remove all risks. At concentrations in excess of 13% the so-called "halophiles" or "salt-loving" bacteria multiply. A special group, the so-called "red-halophiles," are feared because salt cod infected with them has a repulsive smell.

All these facts explain the great variety of precautions mentioned in the preceding pages, for instance, the necessity of removing more water from salted cod than has been achieved by salting alone (drying procedures), the emphasis on precautions during the manufacture of light and heavy salted fish, the importance of low temperatures, and the susceptibility of fish to spoilage at early stages of the salting process.

B. Sliming

This condition, characterized by the appearance of a semigreasy, sticky, glistening layer of yellow-gray or beige color and of a sour pungent smell, occurs especially in light salted cod during water-horsing and during the initial stages of drying.

The optimum salt concentration for slime bacteria on nutrient agar was found to be 6–8%. A total of 93 strains has been found in the slime; 80.5% were gram-negative rods, 11% gram-negative cocci, 5.5% gram-positive cocci, and 2.7% gram-variable rods.

The main reasons for this type of spoilage are inadequate salting and/or extended periods of water-horsing. Lack of freshness of the fish and unsuitable atmospheric conditions, for instance high temperature and relative humidity combined with inadequate air circulation, are important contributing factors.

In comparative water-horsing experiments carried out between 45° and 79°F. the total counts did not increase materially at the higher temperature levels. Apparently a relatively small number of bacteria, which found the prevailing conditions of salt concentration, moisture content, and temperature quite ideal, are responsible for this type of spoilage (Dussault, 1953).

C. RED HALOPHILIC BACTERIA

The red discoloration that takes place when sea water is allowed to stand and evaporate has been mentioned in an ancient Chinese treatise, written about 2700 B.C. (Beatty and Fougère, 1957). It is caused by red-pigmented bacteria that multiply rapidly at salt concentrations of and above 13%. These microorganisms grow even on the surface of moist salt crystals but, on drying, a 99% reduction in bacterial counts was observed after 2-month storage. This may explain the preference, held by some salters, for "old" salt (Dussault, 1953). Conflicting views have been expressed regarding the survival of red halophiles on dry salt. However, Dussault (1957) presented evidence that high relative humidity of the air promotes growth, and the faculty for growth on moist crystals is limited to impure solar salt whereas C.P. salt is inactive. The red halophiles survive but do not grow in sea water, slime, or soil. Irish moss has been found to supply organic nutrients for them (Harrison and Kennedy, 1922).

Ozone is lethal to red halophiles on salt but only when the relative humidity is 80%. The red halophiles fail to grow in cultures containing 2–4% sodium metabisulfite (Friexo, 1956).

Many salting plants have been severely infected with halophiles. Theoretically this type of spoilage could have been avoided since these microorganisms are absent in mined salt; however, from economic considerations the salt fish producers buy this salt from salt fish consumer countries, which incidentally are also producers of solar salt.

Two groups of red halophiles are distinguished, *Sarcina littoralis* and *Pseudomonas salinaria.* Both are proteolytic and the latter is chiefly responsible for the unpleasant odor of salt fish infected with it. The decomposition compounds are indole, which is identical to the principal smell-carrier of human feces, and hydrogen sulfide, the characteristic compound of decomposed eggs. The latter compound is due to the enzyme cysteine desulfhydrase which requires 25–30% NaCl and the presence of pyridoxal phosphate (Baxter and Gibbons, 1957). Bacto-oxgall inhibits the growth of *Pseudomonas salinaria* but does not affect *Sarcina littoralis.* This serves as a laboratory test (Dussault, 1956a,b). The red halophiles show remarkable resistance. They grow, although at different speeds, between 60° and 180°F., and hence are also called thermophilic bacteria. They are killed by lye or chlorine preparations, but only in concentrations, or after periods of time, exceeding those lethal to other microorganisms. Hypochlorite solutions and similar products should have a strength of 500–1000 p.p.m. of free chlorine and should be acidified for higher efficacy. Lye should be used in 2% solution and powdered chloride of lime should be left overnight on the floors. Floors, walls, equipment, and above all the tanks and butts should be thoroughly washed with excess of clean water, because the halophiles depend so much upon salt that lysis occurs in clean water. Contaminated lots of fish should be destroyed and if possible only uncontaminated salt should be used. The dried product is sometimes sprinkled with fine salt containing 0.4% boric acid before packing in order to prevent reddening during transit and storage in tropical countries. For the same reason the addition of 2% sodium acid phosphate and 0.25% sodium benzoate to the curing salt has been proposed (Hess, 1942).

Low temperatures are advisable at all stages. Temperatures of 45–50°F. are adequate for uncontaminated salt cod, 40°F. and preferably even 35–37°F. for those slightly affected (Beatty and Fougère, 1957).

Experiments with antibiotics were not successful; bacitracin has an inhibiting action, but it was limited to S. *littoralis* and did not affect *Ps. salinaria* (Dussault, 1954, unpublished).

The red halophiles are much more resistant to ultraviolet light than other bacteria. They are also capable of adaptation to salt contents higher and lower than optimal. In the latter cases proteins have a protecting effect. The lowest limit is 6% (Hess, 1942; Castell and Mapplebeck, 1952).

The resistance of the red halophiles against tap water is remarkable. Although 99% are destroyed after 1 hour, it requires a total of 6 hours to achieve 100% destruction (Castell and Mapplebeck, 1952).

The interdependence of cations and enzymes is a well-established fact; the insulins are a typical example. However, it has not been clarified completely why the enzymes of *Ps. salinaria* are not precipitated by the brine concentrations in which they thrive. Research on glycerol dehydrogenase of these bacteria has shown that, probably due to unknown modifications in structure of the enzyme protein, this enzyme is unstable at low salt concentrations (Baxter and Gibbons, 1954).

D. Dun

This type of spoilage consists of peppered spots, which are visible particularly on the fleshy side of salted fish and range in color from chocolate to brown and fawn. It is caused by a mold, *Sporendonema epizoum*, which has optimal growth at 10–15% salt concentrations, 75% relative humidity, and a temperature of 25°C. Some strains appear to have proteolytic activity, but not to the extent that the flesh of salt fish is softened. The small spots (spores) visible on the surface develop a root-like network into the interior. Some species, resembling *Torula minuta*, have been described as facultative halophiles because they grow even in the absence of salt, whereas *Sporendonema epizoum* has been described as a true halophile. Since, however, NaCl can be replaced not only by KCl and $NaNO_3$ but also by glucose, this mold is regarded as an osmophile. The mold is hardly affected by ultraviolet light and its spores survive temperatures as low as 17°F. In contrast to the red halophiles, they are killed by hot water, which is convenient for the disinfection of tables on which strong disinfectants that might affect the taste of fish would be unsuitable. The spores are easily whirled up together with dust when, for instance, dried pieces of fish are crushed by wheelbarrows.

For the prevention of dun a number of proposals have been made, several of which fall under the general principles of sanitation, such as covering walls and floors with zinc paints, a minimum of three washings of the rooms per year, and the use of dry well-ventilated rooms. Any damp organic matter that is soaked with salt may prove a fertile breeding ground, and can be dangerous even if only in the neighborhood of the building. Formalin, R2L, Hyamine, and formaldehyde vapors have been suggested for the rooms, and dips of 30 seconds in 0.8 *M* sodium propionate or 0.1% sorbic acid for the salted fish (Frank and Hess, 1941a,b; Vaisey, 1954a,b; Boyd and Tarr, 1954). Sorbic acid appears to be the most effective of all remedies tried so far.

E. Nonbacterial Damage to Salted Cod

In Section II, E, "Salt and Its Impurities," the effect of the latter on the color was discussed. Another abnormality occurs occasionally, namely, "white spots." It has only recently been found that these spots consist of crystals of disodium hydrogen phosphate, deriving probably from the enzymic breakdown of nucleotides. While there are no indications that the quality (stability, taste, flavor) of salted cod is affected, such products are not classified as choice quality. Three causes exist for this manifestation, namely, a partial drying of the salt bulk prior to storage or transportation, a low temperature of storage, and a slightly alkaline conditions of the fish, indicating an initial stage of spoilage. Exposure to dry air would partially dehydrate the crystals, leaving the dihydrate as a scarcely noticeable white powder (Dyer *et al.*, 1958).

VI. Drying of Salted Fish

A. Introduction

In principle, drying is equivalent to the removal of water from a moist substance. In the case of salted fish this process is carried out in order to improve the keeping qualities further than is obtained by the preserving, bacteriostatic, or enzyme-inhibiting properties of sodium chloride. The most important processes for drying liquids and solids depend upon first vaporizing the water and separating it in this form from the structure of which it formed a part. If air is used to carry away the water vapor formed, the process is called air drying. For salted fish, air drying is by far the most popular method. Two possibilities suggest themselves, the so-called "natural drying" method, whereby salted fish is exposed outdoors to the effect of sun and wind, and the "artificial" method, in which fish are placed inside a so-called dryer. This unit consists of cabinets or chambers, fans, heaters, and controls which maintain constant conditions.

Natural drying was long the only method used for the preparation of salted fish. It is apparently uncomplicated and gives good results, provided the weather is suitable. After the fish have been split, washed, and salted, they are spread on rocks or flakes in the open at locations with sunshine and good circulation of air. Drying on rocks may cause damage from sunburn. This method is therefore in use only in northern countries like Norway, Iceland, Scotland, and Newfoundland. The use of so-called flakes, by which fish are kept about 30 inches above ground level, permits free circulation of air underneath. Wooden flakes of triangular 1-inch strips, spaced at about 3 inches and held together by a frame, have been used, but the most efficient are those made of wire netting stretched across wooden frames.

To be efficient, outdoor drying requires a dry atmosphere, sunlight, and also a slight breeze. Moreover, on very hot days when there is practically no breeze the fish may require protection from the sun, which is secured by placing textile material or small wooden roofs over them. Otherwise cooking or so-called sunburn will occur. Well-dried salted cod can be bent, whereas with "sunburnt" or "cooked" cod the muscles will separate. This fish fetches a lower price. On the other hand if the weather is too moist, sliming or other spoilage problems will arise. The rising labor costs for spreading and piling salt fish, and the considerable losses caused by occasional unfavorable weather conditions, have tended to diminish outdoor drying.

These difficulties are not encountered with artificial drying; this method has replaced natural drying in many localities, often to the economic advantage of the fishing industry. The main reasons for this are that artificial drying allows the process to be continuous (day and night) and permits standardized production of a product of high and uniform quality.

Under unfavorable atmospheric conditions, external dehumidifiers and coolers could be used, but the cost of this equipment is relatively high for a cheap nutritional product like salt fish. However, in most localities artificial drying may be applied successfully without external conditioners.

B. Artificial Drying of Fish

For the general principles, the reader is referred to Chapter 1 in this volume, where the theory of drying is expounded in detail.

In the following sections these principles and their application to various artificial dryers are discussed, with special emphasis on salted codfish, one of the most important products.

1. *General Principles*

a. Mechanism

In the drying process of fish, the constant rate period is very short whereas the constantly falling rate period lasts much longer. These two periods are critical because the surface layer of the fish is still moist, therefore perishable and susceptible to bacterial decomposition. This fact is particularly pertinent for light salted fish, which contains more water than heavy salted fish. It is thus imperative to conduct the drying operation during these two periods at the highest possible rate. One of the purposes of "water-horsing" is to remove excess water from the fish surface. Consequently, satisfactory and efficient water-horsing may result occasionally in complete elimination of the constant rate period and in appreciable reduction of the constantly falling rate period.

In the varying falling rate period, the drying rate is governed by the internal rate of moisture flow and, in general, this period requires more time than the constantly falling rate period. In comparison to the beginning of the operation, the magnitude of the drying rate is quite low. For this reason it is of economic importance to use the most favorable conditions. The rate increases with the moisture gradient between the inside and the outside of the fish. Unfortunately it is impossible to take full advantage of this because it is extremely difficult to obtain first quality products if the moisture content at the surface is too low. Size and thickness of the fish have also to be considered. In the case of small fish, this period is relatively short. With large and thick fish, however, it might be so long that special procedures are necessary in order to reduce the drying time and also to improve the quality of the dried fish.

b. DRYING CONDITIONS

(*i*) *Temperature.* As explained previously, the influence of air temperature in drying is considerable. Even a small increase of only a few degrees may appreciably improve the over-all efficiency of the operation. It is therefore very important to use always the highest feasible dry bulb temperature in the dryer. Figure 3 shows the effect of temperature on the drying rate. The various curves were obtained with light salted codfish (Gaspé cure type) (Legendre, 1955). Unfortunately, fish is very sensitive to heat and may be damaged permanently if its temperature exceeds a certain limit. This limit for fish is usually between 80° and 85°F. However, Fougère (1948) found that capelin may be dried at a temperature of 95°F. without being cooked. It was also observed (Legendre, 1957) that various species of fresh-water fish from Cambodia could be dehydrated successfully with temperatures as high as 110°F. During the constant rate and constantly falling rate periods the surface of the fish is at least partially wet. The evaporation of water has a cooling effect. Consequently the temperature of the fish is always below that of the drying air. At the next stage, namely, the varying falling rate period, the situation is different. The surface of the fish is dry and the temperatures of the air and the fish are identical. The danger of cooking the fish is most pronounced and can be eliminated only by keeping the temperature below the tolerance limits of the fish.

(*ii*) *Humidity.* The relative humidity of the drying air is important for two reasons. It regulates the drying rate and greatly influences the appearance of the final product. It is well known that the drier the air, the higher the drying rate. However with fish, this is applicable only during the first two periods. Thereafter, during the varying falling rate period when the fish surface is dry, it is usually advisable to increase the relative humidity of the air up to around 60% in order to avoid an overdrying of the fish surface. With heavy salted fish, case hardening is encountered when the relative humidity of the air is too low, and the salt crust formed on the surface inhibits further drying. With light salted fish, low relative humidities produce shrinkage which results in surface cracks. To avoid case hardening and shrinkage, the rate of surface evaporation should be kept as close as possible to that of moisture diffusion from the interior to the surface of the fish.

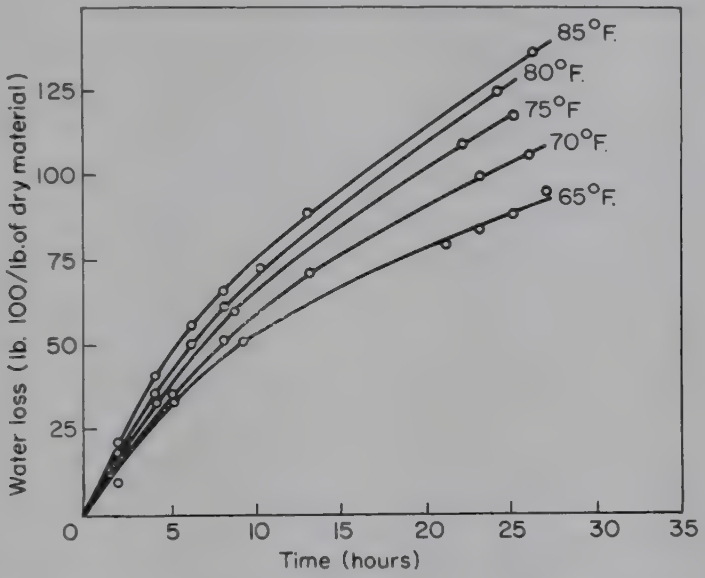


FIG. 3. Water-loss curves showing the influence of temperature on the drying rate. Relative humidity, 55%; air velocity, 300 ft. per min.

(*iii*) *Air velocity.* The effect of air velocity is more or less similar to the effect of relative humidity. Good velocities also favor the distribution of the drying air circulating over the fish and increase the coefficient of heat transfer between the air and the fish. Theoretically, it would thus be advisable to use the highest possible air velocity at the beginning of the operation and, when the surface of the fish is dry, to decrease it to a value which permits adequate circulation and heat transfer. With fish, however, the power necessary to generate high air velocities would be excessive. It is more economical to use a constant air velocity of 250–400 ft. per min., which results in a satisfactory drying rate and adequate air distribution and heat transfer.

c. SPECIAL PROCEDURES

(*i*) *Intermittent drying.* It has been explained that the magnitude of the rate is very low when the surface of the fish has become completely dry and consequently the time required to remove the residual amount of water may be unduly prolonged, particularly with large and thick fish. For this reason it is important to interrupt the drying procedure by press-piling operations. By alternating drying and press-piling, the actual drying operation, exclusive of the time consumed for press-piling, is considerably shorter. The dryer therefore operates at a more efficient level than it would under conditions of continuous drying. This is due to the fact that, in the case of interrupted drying immediately followed by press-piling, the drying rate is much higher at the beginning of each stage. The quality of the fish is an important consideration not to be overlooked. Continuous drying never resulted in a product of uniform water distribution in the numerous experiments of one of the authors (Legendre). The surface became too dry before the removal of water from the other parts of the fish could be achieved.

The drying stage preceding each press-piling should not be too long. If the surface is too dry, the diffusion of water from the inside to the surface will be correspondingly slower, and no time will be gained by such operations. On the other hand, if the drying stage is not sufficiently long and if the surface is not sufficiently dry, there will be grave danger of sliming during the subsequent press-piling stage. The length of the stage depends upon the size and species of fish. The same procedure will apply for the subsequent drying stages. As a general rule, however, they should be much shorter than the first because the water content of the fish is already much lower.

(*ii*) *Press-piling.* The purpose of press-piling is to establish a uniform distribution of water inside the fish by promoting the internal diffusion of moisture to the surface. Therefore, the fish has to be removed from the dryer and piled up in an atmosphere suitable for this purpose. The relative humidity must be high enough so that surface drying will be reduced to a minimum. However, it is very important to prevent condensation from the air on the fish surface. Consequently, a relative humidity of 65% is recommended. The temperature should be about 55–60°F.

The duration of press-piling depends on several factors, such as size of the pile and water content, water distribution, size and species of fish. As a general rule, it may be said that the press-piling has been of adequate duration when the surface of the fish has become wet. Since the diffusion rate is increased by pressure, the surface of the fish becomes moist much more rapidly at the bottom than at the top of the pile. It is therefore necessary to equalize the diffusion process by repiling the fish from time to time; that is, fish at the bottom are put on top of the new pile. This repiling process, moreover, greatly enhances the final appearance of the fish. Because of variations in water content of the semidried product, the duration of the various press-piling stages changes accordingly. The first one is relatively short because the water content is high and water diffuses rapidly. Even after the final drying stage it is important to press-pile the fish for a few days before packing. This contributes greatly to the final appearance and equalizes moisture distribution in the fish.

2. *Drying Salted Cod*

The procedure for drying salted codfish varies somewhat and depends on the type of cure. The initial water content of salted cod is conditioned by its salt content and consequently the drying rate varies accordingly. On the other hand, bacterial contamination depends on the salt and water contents of the fish. With light salted fish the initial water content is high and the salt content is low. Therefore this product is more difficult to process than the heavy salted one because the finishing procedure is actually a race between drying and spoilage. Besides, the drying rate is higher and consequently the heat and air requirements are also much more pronounced than with heavy salted fish.

a. Heavy Salted Cod

The initial moisture content of heavy salted codfish is about 58% wet basis or 138 lb. water per 100 lb. dry material. It must be dried down to about 60% dry basis (37.5% wet basis). This means that about 78 lb. water per 100 lb. dry material, or 32.7% of its initial weight, has to be taken up by the air inside the dryer. This is usually accomplished by employing a temperature of 80°F., a relative humidity of 55%, and an air velocity of about 300–400 ft. per min. Under these conditions the maximum drying rate, which is encountered at the beginning of the operation, is about 4.5 lb. water evaporated per hr. per 100 lb. dry material. The most important factors influencing the drying time of heavy salted cod are the size of the fish and the initial moisture content (Linton and Wood, 1945). Medium-size codfish may be dried in about 40 hr. with only one press-piling procedure. Small fish may be dried continuously in 25–30 hr. Large cod will require about 60 hr. drying and two press-piling periods. If the initial moisture content is as high as 150% dry basis (60% wet basis), the drying time for medium-size fish will be extended to about 50 hr. There is little difference in the drying rates of kench or pickle-cured cod. Kench-cured fish generally have a lower initial moisture content, but the rate of moisture loss from the two types of cure is approximately the same.

b. Light Salted Cod

With light salted codfish, the initial moisture content is about 310% dry basis (75.5% wet basis) and the dried product has a water content of about 60% (37.5% wet basis). Consequently, 250 lb. water per 100 lb.

dry material, or 61% of the original weight, has to be removed by the air. The use of successive drying stages and press-pilings reduces in this case also the drying time and improves the quality of the finished product (Legendre, 1955). Best results are obtained at a temperature of 80°F. and an air velocity of 300–400 ft. per min. The relative humidity of the drying air should be maintained at about 50% during the first drying stage and at 60–65% during all subsequent ones. The first stage is terminated when the moisture content has been reduced to about 120% (55% wet basis). Therefore, the loss in weight should be about 45% of the original weight of the fish. This requires about 30–40 hr. and depends upon initial moisture content and size of the fish. The length of the subsequent drying stages will also depend upon size of the fish. But the conditions of press-piling are of equal importance. In our experience, the use of successive drying stages of 12–15 hours is the most suitable procedure. With small fish, three drying stages are sufficient, but with medium-size fish, four stages will be necessary. With light salted fish the press-piling operation is very important for the final appearance of the product. Between the first and second stages a press-piling of 1–2 days is sufficient. Then the duration of the second press-piling will be about 4–6 days and that of the third 8–10 days. Repiling the fish during the press-piling stage is also of great help to the final appearance of the product.

3. *Artificial Dryers for Salted Fish*

Salt fish dryers have been constructed in different sizes and designs. The tunnel type appears to be most popular. With this type of dryer, heated air circulates over the fish laid on trays until it reaches the required moisture content. The trays may be either stationary or removable. In the latter case they are placed on racks which are carried on trucks for loading or unloading. In certain designs each truck, carrying the trays, is moved progressively inside the tunnel resulting in a semi-continuous operation.

a. HEAVY SALTED COD

The first dryer known to have been successful in drying heavy salted fish commercially is known as the Turbo dryer. This dryer was installed in 1939 in Nova Scotia (Wood, 1947) and is still in operation. It is a continuous tray dryer in which the supply air is dehumidified by a chemical process (lithium chloride). However, its initial cost is relatively high so that this type has not been used extensively in the salt fish industry of Canada. The A.F.E.S. (Halifax Technological Station, F.R.B.[3] of Canada) type, introduced in 1944 by Linton and Wood, is much simpler in design, inexpensive, and satisfactory with heavy salted fish. It has been widely accepted by the industry in Eastern Canada. The dryer contains six bays of 15 trays, 4 × 6 ft. each, and a capacity of about 750 lb. green heavy salted cod. The return duct enables the air to be recirculated. The supply fan blows the outdoor air either through the air heater or directly into the dryer though a by-pass. A mixing damper set in the inlet duct adjusts the relative volumes of incoming warm and cold air to give the desired temperature.

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[3] A.F.E.S. = Atlantic Fisheries Experiment Station; F.R.B. = Fisheries Research Board.

Where steam is available the usual finned steam heater may be used. The fresh warm air is mixed thoroughly with air from the return duct by the propeller fan and the mixture is then distributed uniformly over the fish. In damp weather the supply fan runs continuously and the relative humidity may rise to such an extent that the drying operation must be suspended, unless an additional external dehumidifying system is installed.

b. Light Salted Cod

As explained before, light salted codfish is much more difficult to dry than heavy salted codfish. The air and heat requirements are comparatively large and the relative humidity of the air has to be increased after the first drying stage. Dryers designed for heavy salt fish are not suitable for light salt fish. The failures of initial experiments gave rise to the erroneous opinion that it is impossible to dry light salt cod artificially.

One unit, designed by the Grande-Rivière Technological Station (F.R.B. of Canada) for the preparation of Gaspé cure light salt fish, contains four sections. Two are termed main sections, the other two secondary sections because the air returns by these sections after passing through the main sections. The first drying stage is performed in the main sections and the other stages are completed in the secondary sections. The dryer capacity and the supply of air are such that a relative humidity, maintained at 50% in the main sections, results in a relative humidity of 60–65% in the secondary ones. The dryer includes 16 bays containing 20 trays of 4 ft. by 6 ft. holding about 50 lb. green fish each. The total capacity is equivalent to 16,000 lb. Gaspé cure and the power consumption is 8 H.P. The arrangement of the inlet and outlet ducts permits the air, inhaled by the supply fan, to come either from the dryer or from the outside, according to the position of an automatic damper. The damper is regulated by a wet bulb controller, so that a high relative humidity in the dryer causes the blower to inhale fresh air and to blow humid air outwards. Conversely, when the humidity is low, the air coming from the dryer goes to the blower and is recirculated again.

The dryer was designed for dew points below 55°F. Above this limit it may be found that the relative humidity in the dryer, particularly in the secondary sections, is too high for an economical operation. It is estimated that in a continuous operation 12,000 lb. dried product can be manufactured per week.

Another type of dryer, with approximately the same shape as the A.F.E.S. but twice as large, has been used successfully for light salted codfish in Newfoundland. The main feature of this design is that supply and recirculated air are handled by a single fan.

Light salt fish dryers have the advantage that they can also be used for the preparation of heavy salt fish. The results are excellent.

C. ATMOSPHERIC CONDITIONS

1. *Limitations*

An artificial dryer has a control system for temperature, relative humidity, and air velocity. An additional dehumidifying system may be necessary during warm and moist summer days, otherwise the drying rate may be low and bacterial spoilage may result. In certain regions, artificial drying is even impossible. As stated above, the temperature inside the dryer should be maintained at 80°F. and the relative humidity (RH) at 50–55%. This is possible when the outside temperature is below 80°F. and the dew point below 55°F. (Legendre, 1953). Drying can still be carried out at dew points above 55°F., but at a slower rate so that, particularly at dew points between 60° and 65°F., light salted fish is subject to sliming. At dew points above 65°F. drying is impossible.

2. *Suitability of Atmospheric Conditions*

Since the dew point of the air is an indication of the suitability of atmospheric conditions for artificial drying, a diagram has been prepared (Legendre, 1953) showing the lines of critical dew points as functions of various wet and dry bulb temperatures (Fig. 4). It is possible to deduce whether atmospheric conditions are suitable to produce in the dryer the required conditions of 80°F. and 50–55% RH. Two temperature lines are important: The upper limit (80°F.) is the temperature above which drying is impossible, and the lower limit (55°F.) that below which drying is always possible. Between these two limits artificial drying may or may not be possible. The diagram also shows three critical dew point lines. The 55°F. dew point line is the limit below which best drying rates are obtained. The 60°F. line is the limit at which satisfactory drying conditions are still possible, but at a slower rate. The 65°F. line is the point above which drying is impossible. Therefore, if the point of intersection of the wet and dry bulb temperatures falls within zones A and E, drying is impossible. Within zones B and F, drying is always possible. Within zone C, drying is possible but at a slower rate. Within zone D, sliming may be encountered with green fish because of the high relative humidity.

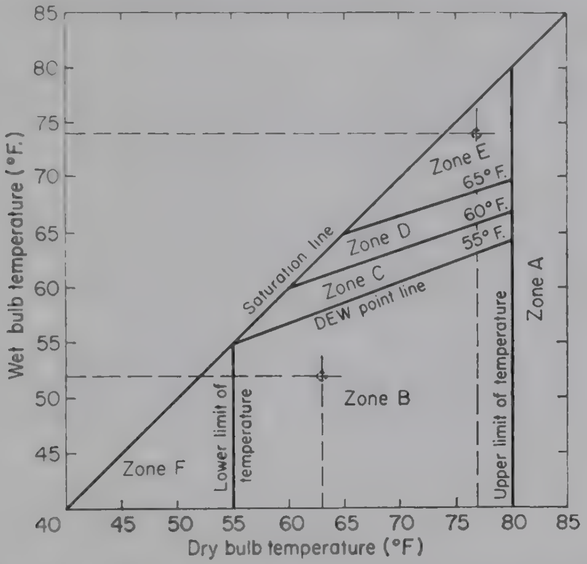

FIG. 4. Relation of the dew point to atmospheric conditions suitable for artificial drying of salted cod.

3. *Air Conditioning Equipment*

The use of air conditioning systems renders a dryer independent of ambient atmospheric conditions.

a. DEHUMIDIFYING SYSTEMS

The removal of water from the air may be accomplished either by refrigeration or by chemical absorption.

When air is being cooled, its relative humidity increases gradually until it reaches 100% at the dew points. If further cooling is applied, the air must give up some water so that its dew point and absolute humidity are reduced. Therefore, some dehumidification may be accomplished by cooling the air below its dew point by means of brine or ammonia expansion coils. As a temporary measure or on a small scale, ice can be used. It is thus possible to condense most of the water content and to reduce appreciably the humidity of the air.

Certain porous solids show great affinity for water vapor on account of the intense capillary action exhibited by the large number of ultramicroscopic pores. Activated alumina and silica gel are typical examples. The latter can absorb up to 40% of its weight in moisture and thus act as a dehumidifier. These absorbents are readily regenerated by the application of heat. They may be used indefinitely without deterioration or loss in volume. There is virtually no limit to the dryness of air that can be attained, so that by selecting the proper size of unit, moisture levels from practically anhydrous air to any higher level may be secured.

b. HUMIDIFICATION

It may happen, in winter for instance, the recirculation alone, particularly during the last drying period, is not sufficient to increase the relative humidity of the air up to the desired level.

Humidification is usually accomplished by use of an atomizing nozzle operated by compressed air. The water drawn into the nozzle is atomized by a small jet of air under high pressure. Steam may also be used by blowing it directly through a nozzle into the air current. In this case, compressed air is naturally not required. This effective and simple method is particularly indicated in designs in which steam coils are used for the heating of the air.

D. THERMOCOUPLE CONTROL

The installation of air conditioning equipment is excellent from the theoretical point of view. In practice, however, the cost is very high. Other ways and means to improve the efficiency of the operation have therefore been investigated.

The required conditions of temperature and relative humidity are quite different during the various stages of the drying operation. They depend upon the state of dryness of the fish surface at each individual instant; as long as the surface is wet the temperature of the air circulating over the fish must be as high as possible and its relative humidity as low as possible.

The temperature of the fish itself is the only limiting factor. When the surface is dry, the temperature of the air must be decreased to about 80°F. and its relative humidity must be increased to 60%. However, with the conventional controlling equipment it is nearly impossible to establish such variable conditions in the dryer. Industrial plants therefore usually maintain a constant air temperature of 80°F. The relative humidity is also kept fairly constant, usually at 50–55% for the whole drying operation. This compromise gives satisfactory results, but only when atmospheric conditions are perfect for drying. Because of the limitations of such methods, a system of automatic controls, that continuously maintains optimal conditions of temperature and relative humidity has been designed, tried, and found to give satisfactory results (Legendre, 1958).

1. *Automatic Control Equipment*

The thermocouple sensing element of the first of three controller systems is inserted in the fish flesh near the surface; it regulates the temperature of the air circulating over the fish in the dryer. The controller is adjusted to 80°F., thus there is no danger of overheating the product. The air is always at the highest permissible temperature. At the beginning of the operation, when the surface of the product is still wet, the temperature of the air is very high, but the temperature of the product approaches the wet bulb temperature of the air, because the rapidly proceeding evaporation exerts a cooling effect on the fish. As evaporation proceeds further, the surface gradually dries out and the cooling effect decreases correspondingly. Consequently, the temperature of the air is automatically and gradually lowered to 80°F., until the surface is completely dry. The second (dry bulb temperature) and third (relative humidity) controllers are adjusted to 80°F. and 60%, respectively. These regulate the operation automatically and according to the conditions required at temperatures above and below 80°F. If the temperature of the air is higher than 80°F., as long as the surface of the product is still wet or partly wet, the relative humidity controller shuts off and the relative humidity of the air is kept at the lowest possible level by the action of the dry bulb temperature controller. When the air temperature reaches 80°F. and when the surface of the product is completely dry, the dry bulb temperature controller stops dehumidifying and the relative humidity of the air is gradually increased to 60%, where it is maintained by the relative humidity controller as long as the temperature does not exceed 80°F.

2. *Advantages*

The system outlined in the previous lines has several advantages over the conventional method. The improvement in performance is found under favorable and unfavorable conditions, with light as well as with heavy salted fish.

a. Favorable Atmospheric Conditions

When atmospheric conditions are favorable for artificial drying, an increase in rate is obtained at the beginning of each stage. The initial drying rate is about twice as great with thermocouple control as with ordinary control. This is very important not only because the drying time is reduced, but also because the danger of bacterial contamination is practically eliminated. Moreover, the system permits an increase in relative humidity as soon as the surface of the fish becomes dry, consequently the production of choice quality light or heavy salted fish is comparatively easy. The possibilities of overdrying the surface or cooking are avoided automatically. With light salted fish it is even possible to save one drying stage. Experiments with Gaspé-cured fish have shown that only three drying stages are required, compared with the four necessary with the conventional method. Time and labor for loading, unloading, and cross-piling are saved.

A striking advantage of thermocouple control for the artificial drying of heavy salted fish consists in reducing the possibility of formation of an impervious salt-protein crust on the fish surface. This crust is usually encountered when conditions giving high drying potentials are used with ordinary control. Therefore the use of thermocouple control renders it comparatively easy to obtain a product of good quality, in spite of its high drying rate.

b. UNFAVORABLE ATMOSPHERIC CONDITIONS

It has already been shown that, with ordinary control, perfect drying conditions are obtainable only when the outside temperature is below 80°F. and the dew point below 55°F. However, the thermocouple system of control maintains conditions in the dryer permitting perfect operation at much higher dew points. As long as the surface of the fish is still wet, there are practically no limits as regard temperature, and good results can be obtained as long as the dew point does not exceed 72°F. When the surface is dry, the temperature must be below 80°F. and the dew point in the vicinity of 65°F. However, since there is no moisture at the surface, sliming is not encountered and drying is still possible, although at a reduced rate, with dew points up to 68°F.

This has been confirmed by drying experiments made under unfavorable atmospheric conditions, that is, when artificial drying would have been impossible with ordinary control. The drying rates obtained with the new method and without an external dehumidifier were of the same order as with ordinary control if used under favorable atmospheric conditions.

The method is based on the general theory of drying and can therefore be used for the artificial drying of any other product, provided the highest temperature that the material tolerates and the lowest relative humidity that will give a product a good quality are known. The controls need only be adjusted for these limits and ideal drying conditions will automatically be maintained at each instant of the operation.

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CHAPTER 5

Marinades

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I. Characterization and Concepts

Fish marinades are characterized by typical odors and flavors; these arise from the treatment of fish or parts of fish with vinegar and salt. This treatment simultaneously brings about a refinement, i.e., conversion of the raw product into food, and a certain preservation. The resulting odor and flavor effects are accentuated by the addition of various spices and covering liquids. The preserving principle is the combination of vinegar and salt (in cooked and fried marinades there is also brief heat treatment). Since it is not feasible, for reasons of taste, to increase the amount of additives in order to suppress possible spoilage, marinades can be kept only for a certain period of time; they are therefore classed among the semi-conserves. Additional preservation by heat sterilization is in general not possible since their characteristic nature would then be lost. Only fried marinades can be treated in this way, to some extent.

On the basis of preparative procedures, cold, fried, and cooked marinades may be distinguished. In cold marinades, or marinades proper, the fish are treated in a so-called finishing bath[1] with a relatively high vinegar and salt content in which they are kept for about a week. In contrast, fried marinades are processed by heating in oil or fat, and cooked marinades are prepared by bleaching[2] in vinegar-salt solutions. The only property in common with the cold marinades, then, is their decidedly acid character, caused by the acidic brines or sauces in fried marinades and by the acidic jelling in cooked marinades.

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In the guiding principles for the evaluation of fish products, elaborated by the Federal Association of German Fish Industries (1957), therefore, the term "marinades" has been dropped for the first time with reference to the latter two groups of products, and the terms "fried fish products" and "cooked fish products," respectively, have been substituted for it. The pH value of 4.8 serves to delineate them from sterilized products likewise prepared with acidic brines or sauces, but which are less acid.

II. Individual Products

Since marinades are products made primarily in Europe and in particular in Germany, the use may be permitted in each instance of the terminology developed along the guiding principles indicated above. Accordingly, marinades (called "cold marinades" in the previously used terminology) are fish products consisting of fresh, frozen, or salted fish or portions of fish processed by treatment with edible acids and salt with the use of adjuvants for seasoning and bleaching and put up in brines, sauces, creams, mayonnaise, remoulade, or oil.

A. COLD MARINADES

In Europe, only herring and sprat are really suitable for the preparation of cold marinades. Both yield a delicate product of fine taste if handled properly. The terminology for the various cold marinades is based essentially on the type of preparation; the presence or absence of the dorsal fishbone is an important criterion.

The chief product is pickled flesh of herring obtained after the head, viscera, and central bone have been removed in such a way that the two fillet lobes are still connected in the back. This is a semi-prepared product, which is sold as such (previously by the name of "saure Lappen" meaning "sour lobes"). "Bismarck herring," "marinated herring fillets," and "collared herring" are derived from it. Bismarck herring are put up in clear vinegar brine with black pepper, mustard seeds, and slices of onion. If the two halves of the fillet are separated the product is called marinated herring fillets, or marinated herring fillet pieces when the fillets are further subdivided transversely. The clear cover brine is then usually replaced by a covering sauce, mayonnaise, or remoulade. Collared herring are prepared from rolled, pickled herring flesh, with seasoning consisting of pickled cucumber and onions placed in the center of the roll. The tail section is previously removed. Fork-sized collared herring are bite-sized small collared herring with or without skin.

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[1] The term "finishing bath" may be considered synonymous with "pickling bath," "marinating bath," or "garbad," as may appear in other literature.

[2] The term "bleaching bath" has the same meaning as the term "blanching bath" sometimes used in other literature.

The prototype of marinades with a central bone is the so-called "delikatess herring," which is eviscerated and headless. Pickled or marinated herring is prepared principally from salted herring (but also from fresh herring) with or without heads. It originally gave rise to the cold marinades. Because of its hearty taste, it is still prepared by many housewives or offered by restaurants with the note "prepared home-style." Preserved herring also belong to this group of marinades, manufactured from salted herring. They differ in general because the central fishbone has been removed.

The last group to be considered is that of the "crown sardines" or "Russian sardines" which are not derived from sardines, as the name might suggest, but rather from small herring in which the viscera and the head have been removed. Sprat may also be used to prepare a similar product.

For cold marinades, a vinegar-salt cover brine is employed containing whole spices and slices of onions, which at the same time serves to give a garnishing effect. To soften the acid taste, vinegar treated with a saccharin may be used since there is danger of fermentation if sugar is added. Besides such pickling solutions, special sauces and mayonnaise are employed. Marinades, prepared from selected raw products and packed with particularly tasty pickling solutions, sauces, etc., or other valuable additives, are considered luxury marinades. If necessary the skin, especially the dark ventral skin, is first removed. These products may not, however, be prepared with the use of bleaching agents or saccharin.

B. COOKED MARINADES

Cooked marinades are made with fresh or frozen fish or portions of fish, processed with salt and edible acids and then heat treated. Seasonings or jelling substances may be added. Special covering sauces are also employed.

Since all the products of this type, with the single exception of seasoned eel, are packed in a jelly, they are termed jellied products. In addition to herring, the following are made into jellied products: eel, thornfish, mackerel, river lamprey, smelt, and other marine fish as well as shrimps and mussels.

To make herring in jelly, use is commonly made of pieces (chunks) of eviscerated herring, divided transversely to the central bone; nowadays the central bone is usually removed. To make collared herring in jelly, fillets are rolled around small pieces of cucumber with spices. If smoked bacon fat is used as a further additive, the term "collared herring with bacon" is employed. Eel in jelly and thornfish (spiny dogfish) in jelly correspond to herring in jelly in type of preparation. Fish jelly made from (diced) salt-water fish flesh (especially from gadids) also belongs to this group. A transition to the fried marinades is provided by fried herring of various types, such as fried fillets and fried collared herring in jelly. Finally, buckling fillets and smoked collared herring are also made into jellied products.

C. FRIED MARINADES

Fried marinades are fresh or frozen fish or parts of fish which are fried, baked, or broiled in oil or fat with or without breading and covered with vinegar solutions or sauces.

In contrast to the cold marinades, the raw products for these items include many types of fish in addition to herring, for example, eel, river lamprey, haddock and other gadids, smelt, and several types of flatfish.

Most fried fish are prepared and eviscerated, generally with the head removed but usually with the backbone remaining. Frying with the head and viscera is no longer in accordance with practice and should be permitted only with river lamprey. Another common procedure is the frying of herring chunks and fish cutlets, meaning fish cut transversely to the central bone; the corresponding portion of the backbone remains in the flesh. A specialty consists of fried collared herring prepared from rolled herring fillets sprinkled with spice grains. Spices are also in the center, similar to what was described for collared herring (Section II, A).

Fried fish products are in general packed in a spiced vinegar pickle (malt vinegar); fried herring fillets, on the other hand, may be put in a piquant covering sauce, e.g., the skumbria sauce of the Baltic states.

III. Manufacturing Procedures

A. COLD MARINADES

1. *Pretreatment*

As soon as the fish arrive in the plant, they must be freed of dirt and scales as rapidly as possible. This is most easily done in so-called drum washers which guarantee careful treatment. With particularly soft products, first a bath of 8–10% salt for about 1 hour to achieve hardening is recommended. The drum washers also provide the possibility for a continuous process. The products are then decapitated, eviscerated, and deboned, according to type of product, in modern deboning machines, a procedure also employed commonly in the production of sterile preserves. To conduct the washing after cutting would be less satisfactory from a sanitary point of view. The cutting involves spreading of filth and bacteria in the flesh.

The fish or portions of fish are subsequently placed in a second cleansing bath, the so-called exsanguination bath in which the blood is removed as completely as possible from the flesh. This is facilitated by the addition of 3–5% salt, but fish should not be kept in this solution longer than a half-hour, since there is danger of reverse diffusion.

For transport from catching grounds to processing plant, herring are usually sprinkled with salt. In this procedure an uneven distribution of salt cannot be avoided. Such inequities may be corrected in the blood-removing bath. In earlier days it was customary to carry out a bleach by addition of hydrogen peroxide up to 50 g. of 30% hydrogen peroxide solution to 100 liters of the blood-removing bath. Regardless of the legal situation, this type of bleaching is costly in terms of aroma losses and enhances rancidity. This method has therefore been discarded, particularly since the dark ventral skin is also removed in modern deboning machines. A small degree of bleaching can be achieved by addition of 0.5% acetic acid to the bath. The fish can in this case be allowed to drip dry on the surface in order to avoid subsequent dilution of the vinegar-salt bath through adhering water. Following this pretreatment, the product is introduced into the softening (finishing) bath.

If salted herring are to be used, they must be soaked prior to cutting, preferably by holding under running water for 24 hours. In products which are not to be deboned, a cut must be made with a knife along the central bone to allow better penetration of the finishing bath liquid into the dark flesh stripes of the salt herring. After cutting, the fish are soaked for an additional 4 hours. Complete desalting is to be avoided. Salted herring in which oil decomposition has taken place are not suitable for the preparation of marinades.

2. *Finishing Bath*

The proper composition of the finishing bath, the ratio of fish to liquid, and the exact manner of treating the product are of decisive importance to a successful final quality. Acetic acid is naturally the most important ingredient of the pickling solution. But without an adequate portion of salt the softening process would proceed too far, and in particular the skin would become detached from the flesh. While acetic acid softens the fish flesh, it is hardened by the salt. On the basis of empirical experience, salt should be in an amount 1–7% higher than that of acetic acid, depending on the strength of the finishing bath. The ratio of fish to pickle liquid must be balanced through so adjusting the acetic acid concentration that the finishing bath at the end of the manufacturing process has an acetic acid concentration of at least 2.5%. Since the keeping quality is reduced with increasing temperature, this concentration must be raised during the warmer seasons of the year. It depends in addition on the water content of the raw products (see below). The more pickle liquid used, the easier it becomes to stir the contents but the total amount of liquid and vinegar required is increased.

The most common vessels for pickling until recently were large open wooden vats or basins protected by acid-fast tiles. These vessels were set up in basements or cool rooms. The ratio of fish to pickling liquid was 1:1 to 3:2, depending on the available vessel volume. Further increase in the amount of fish per volume is not possible because the vinegar-salt concentration then becomes so high that the specific gravity of the finishing bath rises above that of the fish. As a consequence, the fish would then move to the surface and protrude from the liquid. This would lead to defective products. In the last few years, therefore, finishing in closed vats (mostly in Norwegian barrels holding 114 liters) has come to the fore. In this way the vats can be stacked in several layers and the products transported in the vats. In this case 80 kg. herring are generally placed in 35 kg. finishing bath 2.3:1 with 7% acetic acid and 14% salt. For pickling in open vats a 3:2 ratio of fish to liquid with 6% acetic acid and 10% salt is considered best.

The content of acetic acid required in the finishing bath can be calculated according to the formula $E = 0.125\ [20 + 0.3(H_2O + \text{protein})]$ for open vat refining at 3:2, or $E = 0.083\ [30 + 0.7(H_2O + \text{protein})]$ for closed vats if the marinating solution at the end of treatment is to contain 2.5% acetic acid. Corresponding formulas can be set up for every ratio between fish and liquid as well as for other percentages of acetic acid in the final finishing bath. Under otherwise identical conditions, 3.5 kg. acetic acid is required for 100 kg. herring with a water content of 60% in open vats, and 2.9 kg. acetic acids in closed vats, still assuming a final acid concentration of 2.5%. In general, the liquid is not weighed out but measured by volume since this is simpler. It is true that with a higher salt content the specific gravity of the finishing bath becomes greater; in closed vats the acetic acid content in the final liquid is raised by 0.2% due to this factor. But this error can be neglected, the more so since it provides a safety factor.

In order to be on the safe side, when the fish have a high water content of 72%, protein 16%, and fat 10% (the lowest figures acceptable for the preparation of cold marinades), calculation of the amount of acetic acid in the original pickling solution is obtained simply by multiplying by the ratio factor, as for example by the fish:liquid ratio of 3:2, resulting in 2.32 in open vats and 3.05 in closed vats.

For marinades of salted herring, a finishing bath with 5% acetic acid and 3% salt is recommended at a fish:liquid ratio of 2:1. The addition of hydrogen peroxide as a bleaching agent up to 60 ml. 30% solution per 100 liters of the pickling solution is desirable. However, the legal provision of each country must be borne in mind.

The essential factor for preservation is the acetic acid. Therefore all portions of the fish must be brought in contact with the acid, uniformly and quickly. To achieve this goal, it is advisable to place the fish in the pickling bath, to "slap them in," one by one; fillets which hang together are folded back. In closed vats, this precaution is quite essential. It is further necessary that the entire amount of the marinating solutions be added not all at once but in portions, layer after layer, in the way commonly employed in the salting of herring. Otherwise the marinating liquid may become too diluted by water diffusing from the fish tissue. This precautionary measure may seem time-consuming and expensive, particularly since it has been carried out manually until quite recently. Nevertheless it is crucial to satisfactory marinating. According to a recent German patent, this procedure can be mechanized. The addition of marinating liquid can also be simplified by the use of dosimeters (Bruhn, 1956). Loss in weight of the fish at the end of the marinating amounts to about 15%.

During the pickling period which is concluded in 3–7 days, depending on temperature—optimally at 10–12°C.—it is necessary to ensure by repeated stirring, particularly at the start, that the various portions of fish do not stick together, as this prevents rapid penetration of the acetic acid into the center of the product. In open vats stirring is done with broad wooden poles; in closed vats, mixing is achieved either by rolling when taking the barrels to storage or by rotating them on special rotor machines. Upon completion of the finishing treatment, the product is either placed in coolers or packed immediately, as required.

3. *Packing*

For packing, the fish are removed from the barrels, rinsed briefly, and poured onto sorting tables. A successfully completed finishing process can be recognized by the condition of the fish flesh. It may no longer be glassy or shiny in the innermost portions of the flesh; red spots indicate defective finishing. Such products do not keep and must be discarded. It is further advisable to look for damaged products; one or another fish may have to be cleaned again if necessary.

In addition to wooden barrels, the packaging materials may include tin cans of various sizes, depending on whether the product is intended for retailing to the ultimate consumer. The most common sizes are cans with a content of 6.6 or 3 liters (diameter 230 mm., 170 mm. or 83 mm. high). Smaller cans are more suitable for retailing, e.g., diameter of 99 mm. and height of 33 mm. holding 210 ml., or 135 mm. and height of 33 mm. holding 425 ml. (for herring rolls as well as fillet products in sauces and mayonnaise or related products). There are various other intermediate sizes, including rectangular and oval cans. Cans should be provided on the inside with a good lacquer; otherwise there is great risk of chemical damage. Glass and plastic containers have been used recently with success.

The ratio of fish to cover brine or covering sauce is about 2:1; there may be a deviation from this ratio under certain conditions, if a fixed number of fish are to be in the can. The cover brine contains 1–2% acetic acid and 2–4% salt, the lower values applying to cold and the higher ones to warm seasons. A particularly aromatic brine is provided by taking the finishing bath liquid, suitably diluted. Bacteria are largely removed by ultra filtration.

The acid taste of the marinades may be softened by spices or by vinegar to which saccharin has been added. The amount of such a compound should correspond to the sweetening power of 2.5% cane sugar. Slices of onion, carrot, or celery or pieces of cauliflower may serve as garnish. These adjuncts must first be pickled; the vegetables must in addition be blanched. If spices such as pepper, mustard, pimento, etc. are added merely for taste purposes, spice extracts are recommended since they are in general germ-free. Special investigations are in progress at the present time to reduce the acid taste by other procedures and to strengthen the characteristic aroma of the product.

Whereas in the case of marinated products the cans are simply filled to the rim with the covering liquid, special filling machines are used for sauce products. The cans are closed with regular sealing machines. Since the covering brine is liquid, the cans must not rotate during sealing. This holds for all marinades.

4. *Recovery of Used Brine*

During the finishing or softening process the fish lose about 15% of their weight by giving off water to the finishing bath, so that this represents almost one half the total quantity even when the initial ratio of fish to finishing bath is 3:2. If the bath had an initial content of 6% acetic acid and a final value of 2.5%, then over half the acetic acid is lost when disposing of the remaining pickling bath. A prerequisite for using such liquid again is good quality of appearance, odor, and taste.

Such used pickle brine may be employed for making up new cover brine by carrying out a suitable dilution to half or one-third strength; under proper circumstances it may even have a very fine taste. Appropriate filtration can remove any turbidity which may have appeared or undesirable microorganisms.

Even under ideal conditions one may use only half the available spent baths in this way. Certain tax regulations in Germany hinder re-use of these old pickle brines. Tax-favored salt may be used in making up new baths, but not for cover brines.

A further possibility consists in the re-use of the finishing bath after renewal through adding acid up to its original level. The reconstituted finishing bath must be filtered to remove turbidity and to eliminate microorganisms. For this purpose, the finishing bath which still contains appreciable amounts of proteinaceous components in colloidal form is treated with suitable precipitants such as hydrogen peroxide (Lücke *et al.*, 1938) or with colloidal silicon. After allowing the mixture to settle, preliminary purification can be carried out by centrifuging and final purification with presses equipped with filters which retain microorganisms.

Since the finishing baths are often colored a very intense yellow, activated carbon or similar materials may have to be added to the material prior to filtering. This type of recovery necessitates certain technical equipment and a special command of filtration techniques, which are frequently not available in small fish-processing plants and are not economic on a minor scale. This regeneration process must, moreover, be checked continuously as to microbial counts.

It is important that the renewal with acetic acid be carried out prior to filtration, since otherwise further turbidity may be produced by addition of the acid. This seems to be the only way in which further development of microorganisms can be averted. This re-use should, of course, only take place once, since the storage of finishing baths for longer periods requires too much space and is too risky from the microbial point of view.

Since the used finishing baths exhibit a higher pH value (about 4.4) than a freshly made solution (about 2.7), it is often assumed that the acetic acid contained in it is no longer active. These fears are not justified because the effectiveness of the finishing process does depend on the titratable acidity. The pH value simply indicates that buffering substances have entered the finishing bath. Since these buffer substances, however, may be amino acids which aid in the development of gas-forming microorganisms, the finishing bath cannot be re-used too many times. Otherwise, too many of these amino acids accumulate and the threshold value for gas formation is rapidly exceeded. As long as more precise investigations on this point are not available, it may be advisable not to try a second re-use of the finishing bath.

B. Cooked Marinades

1. *Pretreatment*

Only fish of highest quality are suitable for the preparation of cooked marinades. Raw products which tend to become rancid easily do not lend themselves too well to the manufacture of good final products. Jellied products should not be strongly spiced. Rather, the specific aroma of the corresponding raw product should be brought out as effectively as possible by the jellied brine. The most meticulous preliminary cleaning to remove dirt and scales is an important prerequisite. It is carried out much in the same manner as described above for cold marinades.

Appropriate machines are used for beheading and evisceration of the herring. By contrast, the backbone is not removed; rather, the herring is cut into chunks. These pieces must be of somewhat larger size than the intended size of the final portions, since they shrink considerably by treatment in the bleaching bath. Other fish may have to be eviscerated by hand. Thorough final cleaning is urgently required in all instances.

The blood is removed by placing the fish for about 30 minutes in a bath with 10% salt; this treatment constitutes at the same time a kind of preliminary salting.

2. *Bleaching*

The products are spread out on flat sieves (about 5 kg. per sieve of dimensions 640 × 55 mm.) and several sieves one above the other are placed in the bleaching bath. At 85°C. the flesh is usually ready in 10–15 minutes. Larger fish or pieces of fish may require longer exposure. The bleaching bath usually contains 1–2% acetic acid, on rare occasions 4% and 6–8% salt, depending on the preliminary salting. The bleaching bath must be renewed from time to time. Instead of bleaching in a vinegar-salt solution, the fish may be refined in a steam cabinet.

As soon as the product has left the bleaching bath, it is rinsed free of adhering fat and protein foam and cooled with cold water.

3. *Packing*

After cooling and air-drying it is packed. For retail sale the jellied products are packed chiefly in four-sided cans (240 × 230 × 40 mm. for

3 × 4 portions, or 240 × 230 × 71 mm. for 24 portions in two layers). If the product is to be sold locally, making lengthy transportation or storage superfluous, glass or porcelain vessels are used. Each unit weighs about 140 g. and contains 70 g. fish, since jellied products normally contain fish and jelly in about equal proportions. In unpacked products, the jelly portion must be larger (1 part fish and 3 parts jelly); otherwise there is danger from premature drying of the jellied fish that the pieces may protrude, leading to possible mold growth on the exposed surface. If the product is to be sold in closed containers to the ultimate consumer, small round cans (99 × 33 mm., 135 × 33 mm., and even 160 × 48 mm.) may be used. Plastic containers and paraffin-coated paper cup packs may be employed in this instance. Tin cans should be lacquered.

The concentration of acetic acid in the jellied brine is of decisive importance, since it determines the pH value of the entire product and thus its keeping qualities. At the usual ratio of 1:1 between fish and marinating medium, the latter must contain at least 1.9–2% acetic acid. In summer, it is preferable to raise the concentration still further. The salt content should be correspondingly about 3%; in attaining this level, the presalting of the raw product must be taken into account. The required amount of gelatin depends on its quality. The storage temperature of the cooked marinades exerts some influence. In general a 4–5% concentration of gelatin is appropriate. Since gelatin is very heat-sensitive, care must be taken in the preparation of the jellied brine that the temperature does not rise above 70°C. Spices and saccharin can be added to the jellied pickling brine. In the filling, the brine is cooled down to 40°C.

To keep portions of fish from lying directly on the bottom, a 5-mm. layer of jelly is first poured into the containers and allowed to solidify. Then the fish are packed onto the jelly in such a way that the individual pieces do not touch each other. In jellied herring, the backbone is removed by carefully separating the halves of the fish. In cans containing several layers, the jelly must be allowed to solidify each time before the next layer is packed. In order to separate the individual layers, a piece of perforated parchment paper is inserted. Garnishings such as slices of carrot and onion or cooked eggs, etc. are placed on the penultimate layer. Before closing the can, a last layer of jelly is poured on top and covered with a piece of parchment paper to prevent the jelly from adhering to the cover. It is important that this brine, added last, also called the "mirror" layer, fill the can completely. Even before solidification, the can is sealed. The jelly is chilled by special devices such as tunnels, etc. Before the product is shipped, it should be stored for 24 hours in a cooler for reasons to be discussed below.

C. Fried Marinades

1. *Pretreatment*

Cleaning, cutting, removal of blood, and presalting are carried out in the same way as described for cold and cooked marinades. After the fish or fish pieces have been allowed to drain well, they are treated twice in a breading mixture composed of equal parts of rye and wheat flour. After the first breading, the fish must be left to lie for at least an hour to give the meal time for soaking. The breaded fish are then moistened once more and can absorb a second breading. Excess meal must be tapped off gently to avoid the appearance of lumps.

2. *Frying*

Highly varied devices can be used for frying. The original arrangement was an open pan heated directly by coal. The trend toward standardization led to (1) the immersion pan in which the fish are fried, (2) the turnstile pan, and (3) frying devices with conveyor belts arranged in a manner similar to that in the bleaching procedure in which time of passage and heating can be controlled automatically. The time for removal of excess adhering frying oil during transport from the pan is also arranged automatically. For the immersion pans, the breaded fish are placed on metal sieves. Since fish baked in the frying pan according to home-style offer taste advantages over oil-fried fish, mechanization of the former process has also been accomplished. The most recently developed device is so arranged that the fish are just barely covered with frying oil. The technical advantages consist in better heat utilization, smaller oil consumption, and easier water evaporation. The process of packing the fish onto sieves is sometimes eliminated. The conveyor belt permits the attachment of a second belt for the chilling of the fried fish in a tunnel. Then the fish may be taken from the belt and packed directly into the cans.

The frying oil consists of a mixture of oil and solid fat to obtain a pliable film of fat all around the fish. In warmer seasons, one may increase the percentage of solid fat, in colder seasons that of oil.

Frying temperatures in oil should be between 160°C. and 180°C., the latter being optimal. Frying time depends on the temperature of the frying oil, the thickness of the fish, and their water content. Duration of the frying process may accordingly be between 5 and 12 minutes. In immersion pans, the termination of the frying process is indicated by the rise of the fried fish to the surface, since their specific weight is altered by loss of water and absorption of fat.

3. *Packing*

After the fried fish is well cooled, they are packed into cans of various sizes depending on whether they are to be sold in bulk or retail. The ratio of fish to covering liquid is about 2:1, depending on the ability of the fried fish to take up the fluid. In frying, the fish lose about 20% of their water. Much of this is later taken up again from the surrounding liquid. Since this reabsorption does not take place instantaneously, the filled cans are allowed to stand open for several hours and then filled to the brim and sealed. The brine has an acetic acid content of 2.0–3.5% and a salt content of 3–5%, depending on the season and water content of the product. The use of malt vinegar, or vinegar containing herbs or spices, is recommended. A softening of the acid taste by adding saccharin can also be carried out at this stage. Spices in solid form may be pimento, mustard seeds, cloves, or laurel leaves. If the product is to be sold not only by weight but by the piece, the fish must be sorted according to size.

IV. Keeping Properties

In view of the manner of their preparation, marinades are stable only for a limited period of time. For cold marinades, the only available preservatives are acetic acid and salt. For cooked and fried marinades, there is the additional heat treatment step which induces a maximum temperature in the flesh of just under 100°C. This heat treatment is not sufficient to kill all microogranisms. There is, moreover, the possibility of subsequent contamination up to the time when the cans are sealed. The keeping qualities depend largely on storage temperatures, but probably also on the type of bacteria and their temperature requirements. If the finished products are kept at 27–30°C., spoilage must be assumed to occur after about 20 days, even if they were adequately prepared. Spoilage is indicated principally by gas formation which leads to swelling of the cans; with fried marinades it may also involve the appearance of slime, and with jellied products there may be liquefaction. If the cans are not sealed properly or are filled inadequately, jellied products may exhibit mold growth.

There are different types of spoilage, which may be classified according to their causes into physical, chemical, and biological types.

A. Physical Spoilage

Physical spoilage is caused by purely mechanical factors. Cold damage occurs when the products are stored at temperatures below 0°C.

Water expands in the freezing (in cooked marinades the jelly is torn apart by the formation of ice crystals, mayonnaise separates out). Heat damage occurs if the cans are filled in too cold an atmosphere, are too full, and are then stored in a warm environment. With fried marinades, the cans may swell if sealed too early before the swelling of the flesh is completed. Packing damage occurs if the can swells at the time of sealing because it is too full. Finally, compression damage may come about if cans are crushed or deformed in closing or shipping. With very few exceptions the contents of the can are barely altered by physical spoilage. The swelling of the cans is also more or less negligible; it scarcely goes beyond the stage of flipping.

B. Chemical Spoilage

Chemical spoilage is caused by attack of strongly acid products on the metal of the cans, tinned or poorly lacquered. Hydrogen gas is formed. In addition to the swelling the contents of the can may have a metallic taste, caused by metal dissolved in the products, and thus become unpalatable.

C. Biological Spoilage

Of greatest significance is the biological spoilage, which may exhibit all gradations from simple flipping to the most pronounced swelling and even bursting of the cans. There are two subcategories: (1) protein spoilage, derived more or less from the microbial degradation of protein originating in the fish itself, and (2) carbohydrate spoilage, caused by fermentation of added sugars or other sugar-containing additives. A special case of biological spoilage is caused by catalase. If too much hydrogen peroxide is added in connection with the use of raw vegetables, e.g., onions, oxygen is formed by the catalase enzyme.

To avoid these types of spoilage, it is of course necessary to know their precise causes. It is easy to distinguish them by means of gas analyses, bacteriological and chemical investigations, and also by organoleptic analysis. Physical changes are not normally accompanied by gas formation or impaired odor or taste, and thus exhibit no evidence of decomposition. Chemical spoilage leads to the production of hydrogen; the product usually has in addition an unpleasant metallic taste but is not metabolized. Biological spoilage is characterized by carbon dioxide and the quality is greatly affected. In carbohydrate breakdown the pH level drops, while in protein degradation the pH level is higher than normal. A key for distinguishing between major types of spoilage was set up by Meyer (1956a); this can also be applied to heat-processed cans.

V. Chemical Processes

A. COLD MARINADES

Two phenomena obviously dominate the finishing process of cold marinades: (1) the acid reaction of the vinegar, which produces the tenderness so characteristic of marinades and largely due to proteolysis induced by autolytic tissue enzyme (Meyer, 1962a) and appearance of a broth-like taste by liberation of amino acids; (2) the effect of the table salt, causing removal of water and coagulation of protein. The salt at the same time inhibits the hydrolysis and causes it to proceed within desired limits. In addition there seems to be a third effect, namely, the aroma formation ascribed to microbial activities. If acetic acid and salt are added in considerably greater concentration, the microorganisms can no longer survive but the delicate aroma disappears.

Acetic acid acts as a hydrolytic agent, but above all as a preservative. It is supported in its preservative function by salt only in higher concentration, which is already very close to the maximum level compatible with an acceptable taste. Therefore a sharp distinction between chemical and bacteriological processes cannot be made in all instances. Our knowledge of the course of the finishing process is still very fragmentary from the scientific point of view, since it is most complex. Many studies will be required in order to clarify individual phenomena before a coherent picture will emerge of the over-all process. For example, essentially nothing is known in detail of how the hydrolysis of the fish flesh proceeds under the influence of acetic acid (but see Meyer, 1962a). Since these hydrolytic products may serve to enhance the development of microorganisms, this question is of particular significance. Since the betabacteria found in spoiled marinades decarboxylate arginine and glutamic acid, one or both of these amino acids must be formed during the acid hydrolysis. Similarly, whether the antagonistic action of salt is based only on the removal of water and/or coagulation of protein, or whether other factors contribute to inhibition of the hydrolysis, needs to be clarified.

As soon as the finishing bath comes in contact with the fish, a diffusion of acetic acid and salt takes place into the tissue of the fish flesh until a concentration equilibrium is reached. This proceeds relatively quickly. An equilibrium between vinegar and salt in the finishing bath and in the fish tissue is reached in about 24 hours, salt requiring slightly more time than acetic acid for full penetration. Nevertheless the complete finishing of the fish flesh, presumably due to a certain hydrolysis of the tissue, requires a somewhat longer time (Meyer, 1961b).

In following the fate of the acetic acid and that of the salt, the salt content of the final product is found to correspond rather closely to theoretical estimates, whereas it is not possible to account in the same way for the final amount of acetic acid. This may be shown by an example. Herring with 65% water were placed at a ratio of 3:2 in a finishing bath of 5.6% acetic acid and 7.6% salt. If this acetic acid is divided between the water in the fish and in the brine and an equilibrium is reached, the theoretical acetic acid content in the finishing bath after treatment would be 2.82% acetic acid. But actually only 2.45% acetic acid was found, and thus 13.1% of the total acid was missing; these discrepancies are frequently larger. It is assumed that some acetic acid is bound to the protein, but this binding undoubtedly also depends on the amount of amines present in the fish tissue.

Assuming that the portion of acetic acid not retained in the aqueous phase is bound to protein, Wille (1948) calculated the amount of acetic acid bound in the fish flesh. He concluded from his experiments that the termination of the finishing treatment is dependent on the amount of acid bound in the flesh; at least 0.8% acetic acid should be present, whereas at 0.6% the fish is not finished. Since errors are easily introduced in view of the uncertainties in determination and calculation of this acetic acid content, the discrepancies referred to would appear to be less significant. One might equally assume that a certain defined amount of acetic acid would be a prerequisite for an acceptable finish.

Recent studies have contributed to the question of the acetic acid distribution in the softening process (Meyer, 1959, 1961a). It was observed that the traditional method of measuring acetic acid in marinades (extraction of the acetic acid with water at 100°C. (212°F.) and titration of an aliquot part of the clear solution with 0.1 *N* natron lye against phenolphthalein) gave far too high values due to buffering substances present in the tissue or due to the protein and its derivatives. The use of steam distillation made it possible to measure in quantitative terms the amount of acetic acid originally in the finishing bath and in the meat tissue. Furthermore, the acetic acid penetrates the fish tissue not only via its water, but is also attached to the protein although possibly as only very loose compounds.

From these distribution conditions, formulas were worked out by which it was possible to calculate in advance the amount of acetic acid (E_1) required for raw marinades (compare Section III, A, 2). The required amount of acetic acid in a raw marinade with a ratio of fish to marinade of 7:3 is as follows:

$$E_1 = \frac{E_2\ [30 + 0.7\ (H_2O + \text{protein})]}{30}$$

where E_2 is the acetic acid content in the final finishing bath, Consequently the formula for a 3:2 ratio is:

$$E_1 = \frac{E_2 \; [20 + 0.3 \; (H_2O + \text{protein})]}{20}$$

Such formulas can be set up for all other fish:marinade ratios. At least during the warm season, a value lower than 2.5% should never be allowed for E_2.

It can be proved with these formulas that with higher water content of the fish flesh, the acid content of the bath must be increased. Consequently in the example given (in Section III, A, 2), 3.5 kg. acetic acid is required at a tissue water content of 60% and protein 15%, while 3.8 kg. acetic acid is required for 100 kg. fish at a tissue water content of 70% and protein 16%. If herring with 10% difference in water content are put into finishing baths of equal strength, then a difference in acetic acid content of 0.2% is to be expected. Thus the differences are obviously not too great and it is therefore sufficient for practical purposes to calculate from the highest water content and the lowest fat content, respectively.

The fish in the finishing bath, lose about 15% of their original weight in the form of tissue water and soluble protein. Larger losses usually reflect spoilage or other defects in the flesh.

Vinegar content in the fish flesh (E_f) at the end of the bath treatment can be calculated according to the following formula, provided the acid uptake is due to a certain binding to the protein and loss of water from the fish tissue occurs:

$$E_f = \frac{(L - d) \cdot E_2}{F - D}$$

where L is the original water content, d is protein, E_2 is the amount of acetic acid in the finishing bath when the treatment is terminated, D is loss in weight, and F is weight of the original fish. One practical example: Herring with 62% water and 16% protein were packed with a 2:3 ratio between the raw fish and the original finishing bath containing 7% acetic acid. A final acetic acid concentration of 2.5% is then to be expected in the final refining bath. The loss amounted to 14.7%. If we put these values into the formula, it reads:

$$E_f = \frac{(62 + 16 - 14.7) \cdot 2.5}{100 - 14.7} = 1.9$$

Values for E_2 of 2.53% and for E_f of 1.97% were found. When lower values are encountered in the final products it must be concluded that the finishing bath was of the wrong composition or that the acid content was reduced through bacterial action.

Hydrolysis of the fish flesh in the marinades is probably predominantly chemical in nature, since protein-degrading microorganisms are mostly acid-sensitive and therefore do not find a suitable medium for growth in marinades. To what extent autolytic enzymes play a role has not yet been clarified, although there have been a number of speculations on this point (Lücke, 1954). It was earlier thought that autolysis was less significant percentagewise. More recent investigations (Meyer, 1962a) indicate that the protein degradation to amino acids is largely a result of the activity of intrinsic enzymes. The acetic acid acts not so much hydrolytically as by creating an acid environment, in which cathepsin has its optimal range around pH 4.5. High concentrations of sodium chloride and of acetic acid tend to suppress hydrolysis, rather than the reverse. Amino acids from the fish protein are formed. These in turn are transformed in various ways by microbial activity when the acidity level allows such organisms to develop. The amino acids are largely decarboxylated, lysine to cadaverine, tyrosine to tyramine, arginine to citrulline and ornithine, glutamic acid to γ-aminobutyric acid, histidine to histamine, and ornithine to putrescine.

The hydrolysis is very temperature-dependent. At low temperatures just above the freezing point, the finishing treatment therefore takes a longer time than at the usual temperature of 10–12°C. This is important for the storage of merchandise ready for shipping. No appreciable losses take place in the cooler, but at higher temperatures it can be considerable. Finally, at very high temperatures the product becomes pulpy. This is noted in particular in incubator tests. Marinades at 37°C. disintegrate to a very large degree because of autolytic hydrolysis, without being necessarily spoiled by microbial action. A temperature of 27°C. is recommended for incubation in the laboratory, since disintegration by hydrolysis still remains within tolerable limits. Increased temperatures not only promote microbial activity but may also place at their disposal larger amounts of protein degradation products.

TABLE I

THE EFFECT OF ACETIC ACID CONCENTRATION IN THE COVERING LIQUID OF FINISHED MARINADE

	Acetic acid content of brine			
	1.5%	1.0%	0.5%	0.0%
Water in fish after 100 days (%)	66.4	71.45	71.70	77.80
Acetic acid after 14 days (%)	2.2	1.9	1.7	1.6
Acetic acid in covering liquid after 100 days (%)	2.15	2.1	1.9	1.65
Brine after 14 days (pH)	4.10	4.10	4.15	4.20
Brine after 100 days (pH)	4.05	4.10	4.15	4.20
Shelf-life at 27°C. (days)	20	20	15	15

As a cover brine a vinegar-salt solution of lower concentration than that of the final finishing bath is used. An example in Table I shows how analytical data are affected by different acetic acid concentrations in the brine. Herring, cut as a double fillet, at the end of the marination contained 59.3% water, 2.5% vinegar, and had pH 4.17. The fish:brine ratio was set at 2:1. It is apparent that the acetic acid content is lowered, the content of water raised, and the keeping properties as a whole reduced by too mild a brine (Meyer, 1962b).

Table II
Acetic Acid Content and pH Values in Relation to Age of Spoiled Marinade

	Age of spoiled marinade (days)				
	0	30	50	50	57
Acetic acid in brine (%)	2.2	2.0	1.24	0.94	0.92
pH	4.33	4.58	4.93	5.17	5.11

In spoiling cans, the amount of acid decreases and the pH value rises (Table II). The samples were taken from an experiment where different preservatives were used on the same product. Amines were formed from amino acids by gas-forming microorganisms, as will be seen below. These amines bind quantities of acetic acid, depending on their amount.

B. Cooked Marinades

The preserving principle in cooked marinades consists in the combined effect of heat and acid in the bleaching bath; it is known that these two factors are more effective when acting jointly. There is a lack of investigations to support this conclusion under the conditions prevailing in marinades. The degree of acidity in the bleaching bath has no influence on the degree of acidity in the interior of the fish flesh, since the bleaching period is far too short to allow diffusion into the flesh (Meyer, 1953). Only surface action is involved. For this reason only a small amount of acetic acid is frequently present during treatment in the bleaching bath or when finishing in an incubator or air dryer. In the bleaching process, 15–20% of the weight, depending on the salt and acetic acid content of the bath, is removed from the product in the form of water. Thus the bleaching bath gradually becomes so diluted that it must be renewed from time to time.

An additional preserving effect is exerted by the acetic acid diffusing into the finished product from acid jellied brines so that an acid environment is created throughout the tissue, preventing the development of microbes. It is important to choose an acetic acid concentration high enough to produce within 24 hours a degree of acidity in the entire fish tissue that will prevent the growth of microorganisms. Diffusion from the jelly does not proceed as rapidly as in cold marinades and may be complete only after 8 days under certain conditions (Meyer and Kietzmann, 1958).

As in cold marinades, only a portion (about 15%) of the acid is used. The fish flesh has somewhat higher acid values than correspond to theoretical estimates. These additional amounts, small as they may be, are presumably bound via adsorption. The water content of the bleached raw product has some effect on the vinegar content of the flesh; 10% lower water content reduces the acetic acid content of the fish and raises that in the jelly by about 10% of its value. With 1.9% acetic acid in the original jelly and a raw product of 70% water, about 0.95%acetic acid is found in the jellied brine and 0.75% in the fish flesh at the end of the diffusion. These values are all considerably lower than the corresponding ones in cold marinades.

C. Fried Marinades

During frying, temperatures below the boiling point are reached in the interior of the flesh, although considerably higher temperatures prevail in the surrounding medium (Küchler, 1941). Understandably, these temperatures must remain lower as long as the fish still contain water. Only in the outer layers, particularly in the breaded layer, are higher temperatures reached; the flesh takes on a characteristic dark color and the typical aromatic components of fried products are formed. In the course of this process, the fish lose 20–30% of their weight in the form of water, depending on length of time, temperature, and thickness of the flesh or more correctly the relative surface. Herring, originally containing 67.2% water, 18.3% protein, and 12.6% fat, contained after frying 53.0% water, 26.5% protein, and 18.5% fat (Anonymous, 1950). The fried fish make up for this water loss to a very great extent during holding storage in the cover brine. But it must be kept in mind that the capacity for swelling is diminished due to the protein denaturation. In the example cited, the products increased in weight by 23% in 9 days. The absorption of water is thought to be independent of the particular vinegar and salt content of the brine. After 2–3 days, diffusion into the fried fish comes to an end. At the acetic acid concentration most commonly used, 2.5%, the final brine contained 1.3% and the fish flesh 1.2%; at an acetic acid concentration of 3.4%, the corresponding values were 1.8% in the final liquid and 1.6% in the fish flesh. If these values are compared with those of cold and cooked marinades, it is found that the acid content of the fried marinades lies between those of the other two.

In order to understand the various factors which influence the degree of acidity in the final product, empirical figures frequently do not suffice, since the analytical values for the raw product exhibit wide variations. Therefore we have calculated theoretically, in Table III, the influence of water content on the degree of acidity of the finished product, in relation to the amounts in brine and in the fish flesh. The starting point was an acetic acid concentration of 2.5% in the starting bath and a fish:liquid ratio of 1:0.8, a frying loss of 30%, and a reabsorption of water to the extent of 23%.

TABLE III

INFLUENCE OF WATER CONTENT OF FISH ON ACIDITY OF THE FINAL MARINADE

Type of product	Water content (%)			
Raw	75.0	70.0	65.0	60.0
Fried	64.3	57.0	50.0	43.8
Finished	70.6	65.0	59.4	53.6
	Acetic acid (%)			
Brine	1.30	1.45	1.50	1.60
Fish flesh	1.00	0.95	0.90	0.85

If these calculated values are compared with those found in practice, the actual percentages of acetic acid once again are lower in the brine and higher in the fish flesh than the theoretical data indicate. It is possible that the higher values in the fish flesh are again due to adsorption. It has not been taken into account in this table that with a low water content of the herring there is at the same time a high fat content. Herring with a high fat content lose considerable amounts of fat during frying; it is probable that this causes an automatic increase in water content of the fried product. There appear to be no investigations on this particular point.

VI. Microbiological Processes

The microbial aspects of marinades are poorly studied. Investigations started immediately prior to World War II were interrupted, but have been resumed in the postwar period.

According to Aschehoug and Vesterhus (1943), *Pseudomonas* and *Achromobacter* species and flavobacteria are the most commonly encountered microorganisms in freshly caught fish, herring in particular. Most of these species have proteolytic properties. They are acid-sensitive and not likely to be found in marinades, since pH values around 4.5 prevent their development. Only spore-formers, primarily from the *B. subtilis* group, are found frequently in lower dilutions, especially if the acid inoculum is first neutralized. Schönberg and Lochmann (1955) hold these spore-formers responsible for damaged products. According to preliminary investigations by the author, spore-formers cannot develop in the acid environment of the marinades but survive because of their spore form. Kreuzer (1957a), on the basis of studies on marinades inoculated with spore-formers, also came to the conclusion that these organisms cannot generally be considered the cause of such spoilage. He leaves open the possibility, however, that in marinades maintained under mild acid conditions they may aid in causing spoilage. The significance of heat in the fried and cooked marinades in terms of microorganisms has already been indicated. Nevertheless, heat does not kill off all germs, in particular ~~not the non~~spore-formers. This phenomenon is known from the milk and other industries. In any case heat has some debilitating effect, since fried and cooked marinades are more durable than cold marinades at the same acetic acid concentration. The possibility cannot be excluded that other factors may also play a role. It should be added that the risk of recontamination is not as great with fried and cooked marinades, since they are not processed intensively after heating. Cold marinades, by contrast, are in frequent contact with the bacteria-rich dressing tables as they are worked up further.

In microbiological studies the bacterial count by the Koch plating procedure is usually employed. There are many uncertainties in this procedure; in particular, only those bacteria are counted for which the correct nutrient medium was by chance employed. Other bacteria, which may well be of decisive importance, may escape detection completely. Moreover, a change in microflora may make it necessary to change the nutrient media. This is rigorously required in the investigation of marinades and will have to be taken into consideration in future investigations.

In experiments on marinade preparations, to give an example, the author worked up a raw product herring with a bacterial content of 85×10^3/g. on broth gelatin and 12×10^3/g. on wort agar. If finishing was carried out properly, no beta-bacteria, to be discussed below, appeared within 10 days, with the exception of a few spore-formers; however, this was not so if the bath was too weakly acid. Bacterial development was observable after 70 days, even at stronger concentrations of vinegar; its extent was inversely proportional to the acid concentration. The number of bacteria in this case decreased relatively on neutral media and increased on acid media. These investigations have not been completed; but we conclude that the original flora is more or less pushed back by an acidophilic flora which was possibly never present in the raw product. In any case, Kreuzer (1957a) has isolated organisms which degrade glutamate with gas formation from marinades prepared under conditions protecting them against secondary infections. But since he obtained no spoiled products in marinating experiments on the ocean, he also believes that the content of acidophilic forms takes place through contamination on land or in the hold of the ship (Priebe, 1962).

A. Cold Marinades

1. *Beta-Bacteria Spoilage*

In spoiled marinades, Meyer (1956b) found the *Betabacterium buchneri* group in predominant amounts; these organisms liberate CO_2 from the amino acids arginine and glutamic acid by decarboxylation and could be considered the cause of the damage. This involved heterofermentative lactic acid bacteria, which in the acid range present in the marinades can meet their metabolic needs from these amino acids in the absence of carbohydrates. Kreuzer (1957a) has confirmed these results. Beside these beta-bacteria, there are other heterofermentative lactic acid bacteria not yet identified and whose metabolism has not been elucidated. They are not capable of attacking glutamic acid with the nutrient media used so far.

Beta-bacteria have been isolated not only from cold marinades but also from fried marinades and several specialties related to the cold marinades. In fried marinades these spoilage phenomena are not as pronounced, since there are only small amounts of free amino acids.

A study was made in laboratory experiments, using pure cultures, of various conditions affecting this group of bacteria, particularly the influence of temperature, pH, salt, various acids, and various preservatives (Meyer 1956b, c). The temperature optimum is 30–37°C. According to Buttiaux (1954), there are beta-bacteria with a growth minimum at 4°C. Salt has a slight inhibitory effect but only at concentrations above 6.5%. The minimal pH value appears to be specific for each acid or, rather, the pH value as such is not as determining a factor for the inhibition as the acid itself, since for example a pH value below 3.0 is still tolerated in weakly buffered nutrient solutions containing hydrochloric acid, while in acetic acid medium the lower pH limit lies at 4.0. Of decisive importance are the concentration and specific inhibitory action of the acid used. In this regard acetic acid, on the basis of its large buffering capacity, has proved superior to all other acids studied, such as lactic, citric, citraconic, or tartaric. Molds, which actually can play a role in marinades only in open containers, are also inhibited most strongly by acetic acid. The question whether better keeping characteristics are achieved by acetic acid than by fermentation vinegar or vice versa has not been resolved. Fermentation vinegar is given preference by some on the grounds of possibly having a somewhat better aroma.

In the decarboxylation of amino acids by beta-bacteria, the corresponding degradation products (gamma-aminobutyric acid, among others) raise the pH value and gradually tie up the acetic acid (cf. Table II). In weak finishing baths or with herring which stick together in the bath, beta-bacteria may cause neutralization of the acetic acid via degradation products, before the marinating acid penetrates the fish flesh. This may lead to formation of undesirable red spots in which an elevated pH value is encountered; such marinades are condemned.

It is of interest that the beta-bacteria are capable of diacetyl formation. One may conclude from this fact that under certain conditions a part of the typical aroma of the marinades is derived from the activity of these otherwise undesirable organisms. In support of this we may cite the findings (p. 179) that the fine aroma disappears in the finishing bath because of too high vinegar and salt contents. The broth-like taste of the marinades may be caused by gamma-aminobutyric acid, formed from glutamic acid by decarboxylation.

2. *Preservatives*

Among the common preservatives, only hexamethylenetetramine has proved effective, even at low concentrations (10–25 mg./100 g.). With benzoic acid and sorbic acid as well as dehydroacetic acid, concentrations are needed which are near the solubility limit of the substances in question. Since in marinade preparation, preservatives can be added to the brine only in the aqueous phase, 2–3-fold amounts are required. But with these preservatives this cannot be done technically.

For the antibiotics (penicillin, aureomycin, streptomycin, terramycin, and nisin), the required concentrations are higher by a factor of about 10 than that of hexamethylenetetramine (Meyer, 1957). The antibiotic nisin from starter cultures appears promising, but extensive technical investigations are needed in order to establish its effectiveness. In marinating practice, higher amounts of hexamethylenetetramine (about 25 mg. per 100 g.) are needed than is indicated by the threshold value in experiments *in vitro* (5–10 mg.). This is related to the fact that an appreciable portion of the hexamethylenetetramine is bound by the fish flesh (Hutschenreuter, 1956). Kreuzer (1957b) reports the relation between temperature and the elimination of formaldehyde from hexamethylenetetramine in marinades. He found the level of hexamethylenetetramine to remain above this threshold value for a sufficiently long time, only if the product is stored in the cold.

The question whether a smaller amount of preservative may be added, if the initial bacterial content is low than if it is high, is answered in the affirmative by Kreuzer (1957). Meyer (1957) answers it in the negative on the basis of investigations carried out at 37°C. On theoretical grounds, he considers it unlikely that differences in the initial bacterial content can play a decisive role. The problem requires further clarification.

3. *Miscellaneous*

Kreuzer (1957a) studied the influence of a combination of salt and sucrose; at a salt concentration of 7%, a sugar concentration of 15–20% was necessary to achieve satisfactory growth inhibition. Inhibition of glutamic acid decarboxylation takes place at lower concentrations.

In the use of glutamic acid or spices containing glutamic acid, caution is needed since overdosage can lead to spoilage. The threshold value for gas development from glutamic acid is about 0.3% (Meyer, 1956b). Since in general it is not known how much glutamic acid is already present in the marinades, this addition should not go above 0.1%.

4. *Keeping Tests*

For the prognosis of keeping quality, Wille and Kühlmorgen (1951) has proposed the determination of a microbial growth factor. This is nothing more than a running assessment of the increase or diminution of the bacterial count. But as was stated, this is based on the assumption of a uniform microflora and the use of suitable nutrient media.

Kreuzer (1953) bases a prognosis of the keeping properties on the course of the titration curves in the final finishing baths. This procedure does not appear to stand a strict test. The characteristics of the titration curves depend on various factors, such as protein hydrolysis products and possibly their microbial degradation products. Similar effects could conceivably be coincidental and depend on entirely other factors.

B. Cooked Marinades

In jellied products, contamination with nonmotile gram-positive rods about 5–6 μ in size was very frequently observed in earlier days; these rods gave rise to lens-shaped colonies in gelatin (Moll, 1929). According to Struve (1929), this contamination could be counteracted by the addition of hydrogen peroxide, by stronger vinegar concentrations, and in particular by the use of high grade gelatin; such contamination no longer occurs.

In cans with cooked marinades, inadequately sealed or incompletely filled, there is an occasional growth of molds, *Penicillium* species. These organisms may develop as soon as they have access to a sufficient amount of oxygen. Such contamination can be traced externally by the so-called shaking test, in which case the contents of the can are no longer firmly fixed. It can easily be avoided by greater care in filling and sealing of cans.

An alleged instance of botulinus poisoning renewed consideration of the question to what extent forms of *Clostridium botulinum* can develop or produce toxins in the acid medium of marinades. The most important types of this organism, in terms of growth and toxin formation *in vitro* in nutrient solutions with different pH values and in cooked marinades with jellied brine of varying acetic acid concentration, have been investigated (Meyer and Kietzmann, 1958). A pH of 5.3 was the lower limit for development.

To a final pH value of 5.1 in the finished product, a corresponding level of 0.9% acetic acid prevails. But since at this concentration diffusion into the center of the fish flesh requires more than 7 days, germs present in the interior of the flesh still have a good opportunity to grow. Botulinus organisms can grow well within 24 hours; therefore, the acid concentration must be high enough so that within 24 hours the pH is definitely below the minimum of 5.3. This is achieved at acid levels above 1.95%. By keeping the product cool, the development of bacteria can be suppressed until the acid diffusion is complete. Gelatin may possibly be a source of infection and must therefore be checked bacteriologically in every instance.

C. FRIED MARINADES

Fried marinades are sometimes spoiled by ropy microorganisms. The product becomes encased in slime and is less suitable for consumption. Küchler (1942) isolated spore-formers of the *B. subtilis* group believed to be causative. Slime formation seems to occur only when contamination is introduced after the frying, and originating in the breading. It is therefore recommended that the breading operation be partially separated from the packing of the fried products. It cannot be concluded from this study whether filament formation was caused only by pure cultures of spore-formers. But it is obvious that other negligence in manufacture may cause this or similar disturbances. Most spore-formers are susceptible to acids.

VII. Improved Shelf-Life; Preservatives

The principal cause of spoilage of cold marinades is, as stated above, the heterofermentative lactic acid bacteria. In fried marinades, slime formers appear; in jellied products, proteolytic microorganisms and others may occur. The technical measures against proteolytic organisms and probably also against slime formers is a sufficiently high content of acetic acid, combined with a corresponding amount of salt. Special precautions need to be taken in order to avoid contamination of fried and cooked marinades.

It is more difficult to avoid spoilage by lactic acid bacteria. Their suppression requires high acid concentrations, in some instances exceeding what is permissible from the point of view of taste; a too marked taste of vinegar and salt can indeed be covered by suitable spices and saccharin but only to a certain degree. An important factor in assuring the shelf-life of marinades is the temperature during storage. The optimum for growth of the lactic acid bacteria is 30°C. Below this level, the development of these organisms is delayed but not prevented. Marinades stored at cooler temperatures (4–6°C.) keep a long time, but as soon as they are stored for any length of time at higher temperatures approaching the bacterial optimum, a development of these lactic acid-producing organisms is to be expected. With the use of hexamethylenetetramine and cold storage, the risks of spoilage are minimal (cf. p. 188).

Among the preservatives, only hexamethylenetetramine seems to be effective in checking microorganisms. There is, however, considerable objection to its use from a medical point of view because of the possibility of formaldehyde formation, unless it can be shown that the small amounts needed for preservation are safe for human consumption. The use of sorbic acid, dehydroacetic acid, and the esters of *p*-hydroxybenzoic acid is hindered from the technical standpoint by their low solubility in water. The use of benzoic acid is further vitiated by the unpleasant taste it gives to the product if added at levels adequate for preservation. Only nisin seems to offer a feasible alternative.

The legal aspects of the use of preservatives will not be discussed here. But it should be noted that in this respect legislation differs from country to country.

The chief prerequisite for the manufacturing of a high quality marinade is the use of high grade raw materials. Every change in their composition affects the marinating process in one way or another. The need for meticulous cleanliness during the entire preparative process is also self-evident. This holds equally true for the containers, working tables, and implements and, not the least, all the ingredients.

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CHAPTER 6

Scandinavian Anchovies and Herring Tidbits

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I. Introduction

Special kinds of canned herring products have long been made in the Scandinavian countries. They are mostly used as *hors d'oeuvres*, but from time to time they have also formed an integral part of the basic food of at least parts of Scandinavia. There is a whole series of various items: anchovies made from sprats (*Clupea sprattus* L.), and all the different tidbits known as *gaffelbitar* in the Swedish smorgasbord and produced mainly from Icelandic herring (*Clupea harengus* L.). Finally, when Baltic herring (*Clupea harengus* var. *membras*), a small-sized subspecies of herring, undergo bacterial fermentation in the presence of salt a specific kind of fermented herring is obtained (*surströmming*). This is a product of entirely different character from the tidbits and anchovies. The fermentation process gives rise to a strong odor but pleasing taste. Other fishes may be prepared in a similar way, e.g., gwyniad (*Coregonus lavaretus* L.), perch (*Perca fluviatilis* L.), and trout (*Salmo salar* var. *trutta* L.). In Norway such fermented trout is known as *rakørret*.

All these products can be characterized as semipreserved. This indicates they have not been submitted to sterilizing or pasteurizing treatment. They contain a specific flora of bacteria, which exerts a certain influence on the flavor of the anchovies and tidbits. In the case of fermented herring they are of fundamental importance. All the active bacteria are, however, haloduric or halophilic, as all these herring products contain rather large amounts of salt, 10–12%. Sugar and several spices are added to anchovies and tidbits; fermented herring is made without additions other than salt.

Moreover, the growth of the bacteria is controlled by conditions in the cans. Anchovies and tidbits are kept under anaerobic conditions during the whole process. They are packed in airtight containers, which are filled with herring and brine. Thus only obligately or facultatively anaerobic salt-tolerant organisms can grow in these products.

Microbial growth is furthermore mostly suppressed by the addition of preservatives, such as benzoic acid or hexamethylenetetramine. Boric acid, used until quite recently by many packers, has been prohibited through recent government rulings. Some manufacturers use no preservatives at all.

The fat content of the raw material plays an important role in the quality of anchovies and tidbits. A high fat percentage is desirable. As herring fat readily becomes rancid, the anaerobic conditions in the containers are of utmost importance in preventing fat oxidation, particularly as these reactions appear to be activated by the presence of salt.

The fermentation of Baltic herring is accompanied by gas formation. In this process therefore the barrels are not entirely filled with herring and brine; some head space is left. It is not known whether the fermentative bacteria require oxygen. The fat content of this herring is lower than of that used for anchovies and tidbits. No preservatives are added in this special type of herring product.

Briefly, the manufacture of anchovies and tidbits proceeds as follows. Fresh herring are packed with dry salt, sugar, and spices. Under the high osmotic pressure created by the salt, fluid is extracted from the herring, salt and sugar are dissolved, and a brine is formed. After a day or two, the container is filled with extra brine and tightly sealed. The containers are allowed to stand for some time, during which the "maturing" of the herring takes place. In this ripening stage the general character of the herring is greatly changed. Owing to proteolytic enzymes from the herring itself, and probably also from the bacteria in the medium, the protein of the muscle tissue is decomposed into smaller peptides and amino acids. The finished product acquires a soft and pleasant consistency. Aromatic substances are formed and, together with the spices, serve to create an appetizing flavor.

In fermented herring, which are packed directly in brine, the degradation of the proteins is evidently brought about by the bacterial enzymes. In this case the aromatic compounds give the herring a distinctive taste and odor, prized by the initiated but hard to tolerate by the novice. Fermented herring is a specialty of the northern part of Sweden.

Different types of semipreserved herring products are sold: (1) beheaded and degutted herring, fillets, or fillets cut into pieces, (2) directly packed anchovies, and (3) fermented herring. Tidbits, matjes fillets, and skinless and boneless anchovy, which belong to group (1), are the most common products.

The shelf-life of these products is limited. The enzymic activity is not suppressed when the maturing period is completed and the bacteria continue to grow. It is therefore necessary to store these products at refrigerating temperature. Under such conditions they keep very well. At higher temperature, the bacteria may start fermentation with gas formation, causing cans to swell, and the proteolytic enzymes may break down the herring flesh to the point of liquefaction.

A. Development of the Scandinavian Herring Industry

The earliest manufacture of this kind of product was the packing of anchovies. It is difficult to say when or in which country this practice started. There are indications in Swedish publications that in the middle of the seventeenth century this type of product was being manufactured in well-to-do rural mansions. The practice gradually spread among other layers of society in both Norway and Sweden. The product was packed in wooden barrels and kegs or sometimes in clay pots. Small Baltic herring were formerly prepared as young anchovy but rarely nowadays. For a history of the industry, the reader is referred to a review by Borgstrom (1950), from which a few salient features will be related below.

Commercial manufacturing started only in the nineteenth century. The first Scandinavian factory packing anchovy in cans is documented in 1841 from Drammen in Norway. This country remained the leading producer of Scandinavian anchovy for several decades. A substantial portion of its pack was exported to Sweden. The Swedish industry started about 15 years later and soon developed in size.

In 1865 it was reported that more than one third of the sprats caught in the district of Bohuslän, the principal fishing region of Sweden, was prepared as anchovy. In 1869 the anchovy industry at Gullholmen, managed by Hallgren was singled out as producing a superior quality product, and received international recognition at commercial exhibits in the United States, Russia, and Europe.

In 1874 more than 5000 barrels of sprats were processed as anchovy at several places along the coast of Bohuslän. Small sprats were used for this purpose, yielding products with a fine aroma and few conspicuous bones. When the technique of soldering cans was discontinued in favor of seaming, the Swedish anchovy industry advanced with rapid strides.

According to a Norwegian description of the Swedish fisheries published in 1869, the Swedish anchovy was smaller and contained less fat than the Norwegian. Consequently it was considered of inferior quality. The finer households of Sweden bought Norwegian anchovies, but most of the Swedish restaurants used the domestic product. This difference no longer exists, and today Sweden is the leading manufacturer of Scandinavian anchovies (Borgstrom, 1950).

The Danish industry for semipreserved herring products started in 1895. A number of canning factories in Denmark now manufacture these products. Earlier this industry was based chiefly on imported sprats, mainly from Norway. Today, fish caught in Danish waters or by Danish fishermen are employed almost exclusively. Anchovy was always a minor item.

In the Baltic, sprats were caught and packed as "anchovy" and certain other products. They were brined and spiced in the ordinary way, as described in a 1671 Swedish publication. In a book on Swedish fisheries (published in Stockholm in 1778), the Baltic sprat, biologically identical to that along the western coast of Sweden, is said to be in all essential respects similar to the sardel. It can be prepared in the same way and renders the same products. No anchovy is prepared from Baltic sprats today.

The manufacture of fermented herring from Baltic herring, a variety or subspecies of *Clupea harengus* L., also has a long history. Not only Baltic herring, but many different kinds of fish were prepared in this manner. In the middle of the seventeenth century, fish of this kind were commonly consumed in large areas of northern Sweden and Norway. This practice probably developed during times when common salt was expensive. People used less salt than was necessary to prevent bacterial growth and thus got a fermentation of the fish. This was not dangerous to health and gave the fish that strange odor and taste characteristic of these products. Most fermented herring nowadays is made and used only as a "delicacy"; it is made on a large scale in factories along the northeastern Baltic coast of Sweden.

Of later date is the manufacture of tidbits. In 1906 Alfred Bovik in Lysekil, Bohuslän, carried out experiments with Icelandic herring. He sent with the fishing boats that went to the Icelandic fishing area some bags with a mixture of salt, sugar, and spices for packing herring in barrels in the same manner as practiced for anchovies. This herring was then cut into pieces and packed in tin cans. The experiment succeeded and the product rapidly made its way on the market. Under a series of

TABLE I

PACK OF HERRING DELICATESSEN IN DENMARK, NORWAY, AND SWEDEN (1927–1960)[a]

Year	Anchovy and skinless and boneless anchovy			Tidbits and herring fillets		
	Denmark	Norway	Sweden	Denmark	Norway	Sweden
1927–29	—	1101.0	4167.0	380.0[c]	392.3	4533.0[d]
1930–34	—	887.4	3533.0	920.0	920.8	4778.0
1935–39	514.0[b]	969.0	4119.4	887.2	848.6	5499.0
1940–44	521.0	466.0	5377.0	354.8	463.8	2680.4
1945–49	533.0	1084.2	5238.2	856.4	1440.0	5678.8
1950–54	402.0	1417.0	4831.8	841.4	1595.8	7178.0
1955	373	1133	4369	1037	1774	7758
1956	365	1051	4863	1095	2033	7062
1957	438	594	2519	1233	1802	7283
1958	358	983	3313	1287	2025	7013
1959	259	879	4164	1234	1612	7656
1960	232	575	—	1211	1602	—

[a] Product weight in metric tons.

[b] Average for 1938–39.

[c] Inclusive of anchovies.

[d] Swedish figures in the years 1927–30 include all semipreserved herring products except anchovies.

trade-marks, with different seasonings and sauces, these products were in great demand in Sweden and also abroad, especially the United States. Production of tidbits is now much greater than that of anchovies (see Table I).

The packing industries originally were small undertakings. The work was done by the proprietor and his family in small boat houses and storehouses. This is still the case in certain localities in Bohuslän, but many grew and presently there are a number of sizable industries. Many remain family concerns. An example is the Ameln Brothers' firm which from the founder, Christian Gerhard Ameln who started in Bergen in Norway in 1838, passed from father to son through five generations. This type of family enterprise is characteristic of the industry.

Manufacturing experience accumulated in the course of time, and the methods employed were kept as secrets within the family concern. Fundamental research was rarely conducted and only in the last decades has work started in this field. The microbiological and biochemical reactions that convert the fresh herring into these delicatessen are far from known in detail.

II. Anchovy

Sprats (*Clupea sprattus* L.) used for manufacture of anchovies are caught mainly in the fjords or just outside the Atlantic coast. Catching methods are the same as for winter brisling sardines, and are dealt with elsewhere (Volume IV, Chapter 6). Fishing starts in the middle of September and ends about the middle of January. During these months sprats have their highest fat content. The raw product for anchovy contains 14–20% fat.

Anchovy is packed in two ways, either in barrels or in retail cans. The first type is used for production of skinless and boneless anchovy, which is packed in small boxes.

Barrel anchovy is packed in wooden barrels, about 95 kg. in each. To this is added a mixture of salt, sugar, and spices such as peppers, mace, coriander, hops, cinnamon, ginger, cardamon, and sandalwood—the last giving anchovies their red color. Saltpeter is also added, together with a preservative, generally benzoic acid.

The rinsed and drained whole sprats are mixed thoroughly on a special table with the proper amount of salt-sugar-spice mixture, each fish being well powdered on the surface and then poured into the well-cleaned barrel, at the bottom of which some of the salt-sugar-spice mixture is placed. The rest of this mixture is put over the sprats. After 1–2 days a brine is formed from the fluids extracted from the fish, in which all the salt and sugar is dissolved. At this moment the barrels are filled up with extra brine of salt and sugar, sealed by a closely fitting lid, and put aside. Generally the barrels are stored outdoors in the cold season; in the spring they are moved into cold storage or refrigerated rooms.

The maturing depends upon the condition of the raw material and the storage temperature. The products packed at the beginning of the season generally ripen faster than later ones. A mature product is of soft and smooth consistency and the backbone is easily removed from the flesh. Judging the proper maturity is a matter of experience. There are no objective methods; the expert can determine this by biting through the back of the anchovy just behind the head.

When the barrel anchovy is mature, it is cut into fillets. Skin and side ribs as well as belly membranes are removed, and the fillets are packed in boxes. These are generally of the flat rectangular type. Filleting, trimming, and packing are done by hand. There are varying methods for cutting and trimming. Each of the workers—mostly women—may have her own method. This gives variation in appearance of the fillets and in payment to the workers, which is so much per can.

The cans are then filled with sauce, a solution of salt and sugar in which spices have been boiled. This sauce also contains a preservative, formerly boric acid as a rule. Since this is now prohibited, benzoic acid with or without addition of hexamethylenetetramine is widely used. The brimful cans are sealed and the product is ready for consumption.

Directly made anchovy is packed in cans (106 mm. in diameter and 55 mm. high) which hold 450 g. For export, cans of 48-mm. height containing 400 g. are used. Essentially the same mixture of salt, sugar, and spices as for the barrel anchovy is used for this product. The packing is done by hand. Some of the salt-sugar-spice mixture is poured in the bottom of the can and the sprats are packed in three layers at right angles to each other. Some of the mixture is sprinkled between each layer and the rest placed on top. This product also contains preservatives.

When all salt and sugar are dissolved—about 2 days later—the cans are completely filled with extra brine and then sealed. Maturing is done at 12–15°C. The cans are turned over each fortnight. Now and then samples are taken out to check the maturity. When finished, the cans are put into cold storage. They are now ready for consumption.

During ripening, several degradation products of the herring protein diffuse into the brine, making it very aromatic. The directly made anchovy has therefore more flavor than the skinless and boneless type, where the aromatic substances are diluted by the new sauce added to the boxes. On the other hand, the latter is "ready-to-eat" while the directly made anchovy must be filleted by the consumer. This is, however, a rather simple procedure as the backbone is very easy to remove; many lovers of anchovies look upon this as part of the delight and a pleasant relaxation.

A. Ripening of Anchovy

The maturing has recently been the subject of extensive investigations by the author (Alm, 1956). Figure 1 shows the changes in drained weight and in amount of brine formed in cans of anchovy packed with 310 g. fresh sprats and 90 g. salt-sugar-spice mixture (12:6:1). All figures are calculated on 100 g. raw herring.

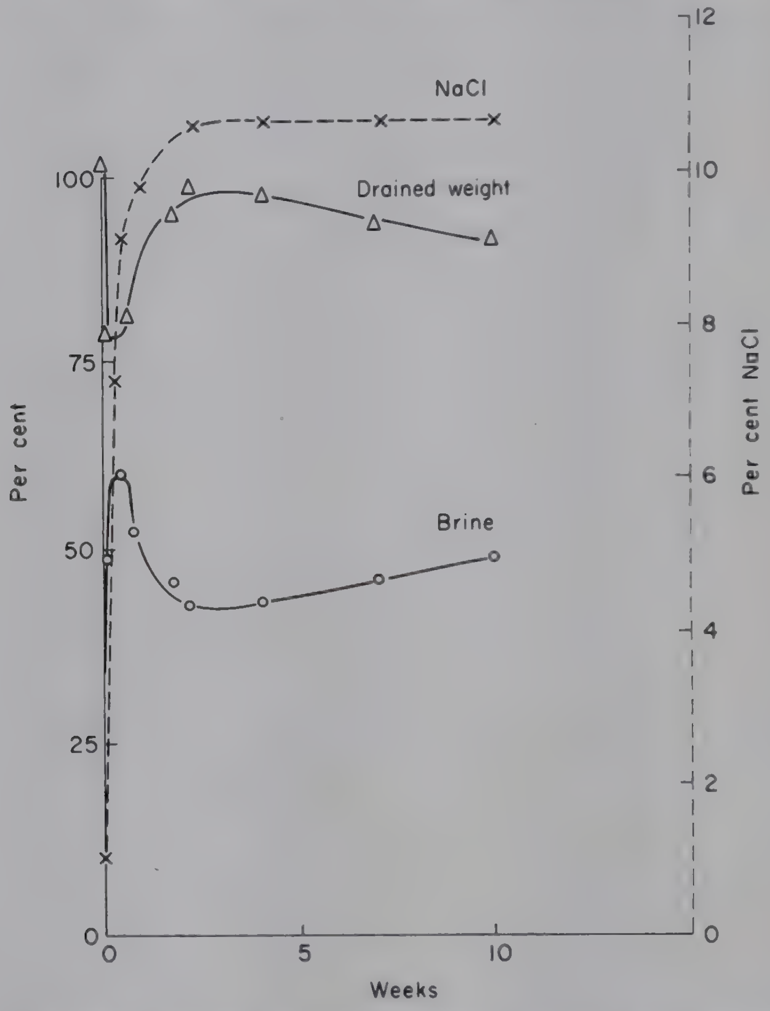

Fig. 1. Changes in drained weight, formation of brine, and penetration of salt into the herring in cans of anchovies during the maturing process. All values are calculated as per cent weight of the fresh herring packed (Alm, 1956).

The curves show decreasing weight of the fish during the first few days owing to extraction of body fluids. At this time the fish is very hard and dry. Later the drained weight increases again when salt, sugar, and water diffuse into the fish muscle. After 2 weeks the system is—broadly speaking—in equilibrium. There is finally another drop in drained weight at the end of the ripening process, apparently depending upon migration of decomposed proteins from the fish into the brine.

Changes in solubility of the muscle proteins at low and high ionic strength have been followed, as well as formation of aminonitrogen compounds (Fig. 2). All values are calculated on the nitrogen content of 100 g. fresh herring. During the first phase of the process the solubility of the protein decreases sharply. This change is most evident in that part of the protein which is soluble at high ionic strength, i.e. actomyosin. Other proteins are little influenced. The insolubility of actomyosin makes the herring hard and dry. Apparently the high salt concentration brings about denaturation of actomyosin, a phenomenon quite similar to the effect of salt on cod muscle, which was studied by Duerr and Dyer (1952).

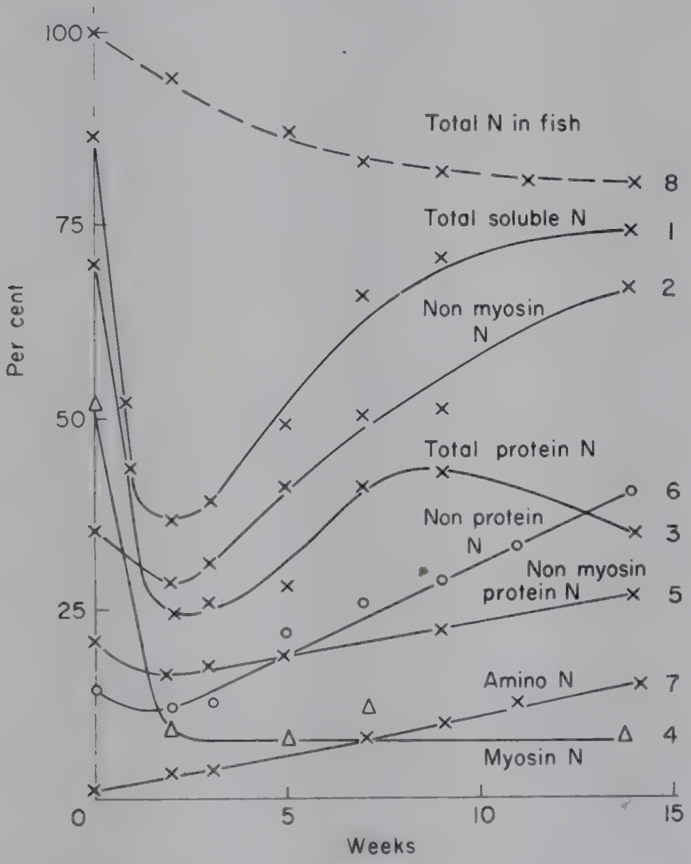

FIG. 2. Total nitrogen and different soluble nitrogen fractions in herring fillets, cut from drained herring in cans of anchovies at varying intervals during the maturing process. All values are calculated as per cent of the nitrogen content of the fresh herring packed (Alm, 1956).

After 1–2 weeks the fish protein solubility has reached its minimum and increases. This is explained by the gradual degradation of the actomyosin into smaller peptides and amino acids, which are soluble at low ionic strength; this can be seen from Curve 2 in Fig. 2. These soluble nitrogen compounds consist of one fraction precipitated by trichloroacetic acid (TCA) (Curves 3–5) and another noncoagulable fraction (Curve 6), this latter increasing more rapidly. There is also an increase in aminonitrogen (Curve 7). Part of the nitrogen fractions diffuses into the brine. The nitrogen content of the drained herring itself drops (Curve 8).

The presence of a whole series of amino acids in extracts of anchovies has been established by paper chromatography. These increase in amount during the course of the maturing process. When the solubility of the nitrogen fractions has reached about the same level as that of the proteins of fresh herring at high ionic strength, the anchovy is mature. At that time it has its specific consistency and flavor. In spite of considerable degradation of its proteins, it maintains its structure and is readily cut into fillets.

III. Tidbits ("Gaffelbitar")

Tidbits are made from Icelandic herring. By agreement between the Scandinavian countries no herring is caught prior to July 1. The fishing area is north and east of Iceland, though not south of latitude 65°N. After spawning along the Norwegian coast, the herring migrates to the Icelandic region. At this time they have started feeding and their fat content is high, 20–24%. The fishing season is completed by September 15.

During the first 2 weeks if the weather is fine, purse seines are used; later the fish are caught by drift net. The price is settled by agreement between the central organizations of fishermen and the packers, but contracts about quantity of delivery, etc. are made directly between the buyer, i.e. the packer, and the fishing boats, most of which are Norwegian. The packer commits himself for at least 90% of their loading capacity but, on the other hand, demands certain quality, etc.—for instance not more than 4 herrings per kg. when the herring is to be used for tidbits. This figure may vary from year to year. Norwegian fishing boats land their catch in the homeland where quality is controlled by an agency of the government. No Norwegian-caught herring can be delivered for export without a permit.

The packer supplies the fishing boats with barrels, fresh from the factory and 114–117 liters in volume, and the sugar needed for each barrel. This is weighed out in bags by the packer, as is also the mixture of spices. Salt is added by measure on board. No preservatives are used in the barrels.

Packing of the herring is done on deck. The herring is killed by cutting off the head behind the gill fins, and bled. Some boats have machines for these operations but it is usually done by hand. Some packers want their herring degutted, others do not. The fishermen follow the directions of the packer. It is said that the maturing proceeds faster when the herring is not degutted.

No further treatment is started before rigor mortis has ceased, i.e., 4–5 hours after catching. Then salt (14–16 kg. by measure), one bag of sugar (at least 3.5 kg., often more), and one bag of spices are thoroughly mixed in a special tray. Spices are about the same as described for anchovy. A layer of the mixture is spread over the bottom of a barrel, and packing starts. Each herring is well powdered in the tray with salt-sugar-spices, and the fish are packed, one by one, in layers with head end and tail alternating. Some of the salt-sugar-spices is spread between each. The packing is done very carefully, no "naked" surface being allowed to touch another. The barrel is filled over the top and should then contain about 95 kg. herring. More than 100 kg. is undesirable. In this case the barrel is too tightly packed, giving an inferior quality.

Soon a brine is formed in the barrels, in the same manner as described for anchovy. With the proper amount of herring, the "natural" brine should cover the herring. The barrels are then sealed, labeled, and stored in the cargohold.

When the boats return home the herring is inspected. As mentioned before, this is done by the Norwegian government. For Swedish boats this inspection is made by the buyer himself. The goods are graded according to size, fat content, weight, and condition of the brine. This should be at least 18° Bé. Payment is made on the basis of quality.

At first the barrels are stored outdoors, when the temperature is low in the autumn and winter. In the spring and summer they are kept in cold storage at 5°C. The barrels are periodically filled with brine, as the wooden barrels are not quite tight. It is important that the herring be well covered with brine, and the barrels full; otherwise the herring may become rancid. The brine constitutes good protection against fat oxidation. As time goes on, the herring becomes more compact, leaving space in the barrels. Therefore, herring is transferred now and then from one barrel to another to keep all the remaining barrels full.

The herring is kept in the barrels until it is mature. The degree of maturity is judged empirically. The rate at which maturity develops depends on several factors. Temperature is important; the lower this is, the longer the maturing time. Ungutted herring has a briefer maturing period than degutted ones. Herring caught at the beginning of the fishing season matures faster than herring caught later. Barrels packed in the early part of July may provide mature herring in October of the same year, while herring caught in September may have to be held until September of the next year. The manufacturer tries to regulate the maturing of his herring stock in order to have raw material for tidbits throughout the year and also work for his employees.

The mature herring is filleted by hand; the skin is removed, and a certain trimming takes place. The fillet is then cut into pieces of varying shape according to the pack in question. There are of course different qualities of herring, and the packer uses a certain grade for each of his packs. For the most exclusive ones only the best raw material is used, and no more is packed of each grade than available raw material quality permits. The pieces are packed into boxes of varying shape or sometimes glass jars, and a sauce is added. This sauce often contains a preservative. Each pack has its specific sauce. This always contains vinegar and sugar, but kinds of spice vary. Mustard and onions often contribute to the flavor of these products. Herring is also packed as whole fillets in oblong cans, normally two fillets in each. These are called *matjes* fillets but are not the same product as the authentic Dutch matjes fillets. After sealing the cans or jars are immediately ready for distribution.

IV. Biochemistry of Maturing

As pointed out earlier, the maturing of "anchovy" consists of marked degradation of the proteins. This is also the case in tidbits (Aschehough, 1952). Whether this decomposition is brought about by proteolytic enzymes of the herring itself, or is a result of bacterial activities, or is a combination of these two processes, is still uncertain. Many observations indicate that the intestines of the herring are particularly important. As mentioned above, maturing is faster in ungutted Icelandic herring than in those eviscerated. Anchovies, which for experimental purposes have been packed with the intestines removed, do not go to maturation. This effect of the intestinal contents may be due to its microbial flora, which give off potent proteolytic enzymes. A second alternative is that the digestive enzymes produced by the intestinal system of the herring itself cause the protein degradation. This latter situation seems to be the case with anchovies.

Aschehough (1952) has made an extensive study of the microflora in barrels of Icelandic herring. She followed simultaneously the changes in herring proteins (Tables II–IX). In common barrels of ungutted herring she found a marked increase in bacterial count between 69 days of storage, when the herring was still immature, and 98 days, when maturing was complete (Table II). In another experiment, performed at the same time and with herring from the same lot except that this herring before packing was treated for 3 hours in 3% acetic acid, she found no increase in bacterial count until the herring had matured, in this case after 69 days. Thus, maturing in this experiment proceeded faster than in the other, and without an increase in bacterial population (Table III). In the first experiment there was a definite lowering of the pH after 98 days (Table VI), which points to fermentation with the formation of acids. This may explain the observed increase in the bacterial count. In both experiments, the increase in amino nitrogen formation was of about the same order, but more volatile bases were formed in the herring not dipped in acetic acid. The herring treated in acetic acid was cut into tidbits and packed in cans with and without a preservative. In about 35 days, vigorous fermentation could be observed in cans *without* a preservative and a correspondingly high bacterial count. In cans *with* a preservative no microbial growth took place (Table IV and V). Consequently, Aschehough's experiments seem to indicate that it is dubious if bacteria have any decisive influence on the degradation of the herring protein. Furthermore, Icelandic herring matures even when eviscerated, indicating that intestinal enzymes are not necessary for the maturing process in this type of herring. This coincides with findings by Almy (1926) on Maine herring. More research is needed on the ripening mechanism. Christiansen (1962) concludes that visceral enzymes control the protein degradation. Several fishes have active proteolytic enzymes in the pyloric caeca. This conclusion is substantiated by the fact that artificial ripening can be induced by adding commercial proteolytic enzyme preparations (Christiansen, 1962); the trouble in this case is to stop enzymic degradation before it has gone too far.

Recent findings seem to indicate that, contrary to earlier assumptions, the meat tissue as such carries proteolytic enzymes of a cathepsin nature. This autolysis has been studied apart from microorganisms by eliminating them through γ-radiation (Hata *et al.*, 1960). In experiments with Dutch matjes herring, however, the exopeptidases (cathepsins) of the muscles are more strongly inhibited by salt than are the endopeptidases of the intestines (Luijpen, 1959).

Studies of the microflora of anchovies show that the number of bacteria growing on common laboratory media with addition of 7% NaCl and 5% sucrose rapidly decline to low figures during the maturing process. Afterwards the count may mount to high levels, but only if fermentation has started. This phenomenon will be analyzed below.

Notwithstanding, bacteria may be of importance in forming certain of the aromatic substances in herring products. This has been observed by many authors (Shewan, 1938; Omland, 1955). Messing (1934) and Jermoljewa and Bujanowskaja (1934) have isolated aroma-forming bac-

TABLE II[a]

MICROFLORA OF SPICE-CURED WINTER HERRING—SERIES 1

Days of curing at 12–15°C.	Organoleptic examination of herring	Average bacterial count at 22°C. (in 1000 per gram)				Average yeast count (in 1000 per gram)	
		Herring		Brine			
		Aerobes	Anaerobes	Aerobes	Anaerobes	Herring	Brine
0		7,000	250	—	—	—	—
21	Taste raw	800	500	600	100	—	—
69	Taste raw	600	70	4,700	200	20	30
98	Ripe Taste good Consistency normal	34,000	15,000	550,000	330,000	22	13
154	Overripe "Sour" Fish flesh red	74,000	50,000	640,000	500,000	0	0

[a] Aschehoug (1952).

TABLE III[a]

MICROFLORA OF SPICE-CURED WINTER HERRING—SERIES 2[b]

Days of curing at 12–15°C.	Organoleptic examination of herring	Average bacterial count at 22°C. (in 1000 per gram)				Average yeast count (in 1000 per gram)	
		Herring		Brine			
		Aerobes	Anaerobes	Aerobes	Anaerobes	Herring	Brine
21	Almost ripe	100	10	340	50	0.050	—
69	Ripe Taste good Consistency normal	50	9	30	500	900	500
154	Overripe "Sour"	3,000	500	5,000	10,000	0	0

[a] Aschehoug (1952).

[b] Acid-treated raw material.

TABLE IV[a]
MICROFLORA OF GAFFELBITAR OF CURED WINTER HERRING FROM SERIES 2[b]

Days of storage at 22°C	Condition of can	Organoleptic examination of gaffelbitar	Average bacterial count at 22°C. (in 1000 per gram)				Average yeast count (in 1000 per gram)	
			Gaffelbitar		Spiced sauce		Gaffel-bitar	Spiced sauce
			Aerobes	Anaerobes	Aerobes	Anaerobes		
7	Normal	Normal	1,000	0.1	260	0.5	0.4	17
35	Blown	Taste sour	10,000	15,000	52,000	17,000	0.5	0
59	Highly blown	Taste sour Consistently soft	2,400,000	2,500,000	2,900,000	2,800,000	0	0

[a] Aschehoug (1952).

[b] Packed in cans with spiced sauce without preservatives.

TABLE V[a]
MICROFLORA OF GAFFELBITAR OF CURED WINTER HERRING FROM SERIES 2[b]

Days of storage at 22°C.	Condition of can	Organoleptic examination of gaffelbitar	Average bacterial count at 22°C. (in 1000 per gram)				Average yeast count (in 1000 per gram)	
			Gaffelbitar		Spiced sauce		Gaffel-bitar	Spiced sauce
			Aerobes	Anaerobes	Aerobes	Anaerobes		
7	Normal	Taste and consistency normal	900	0.6	14	0.4	0.4	0.6
35	Normal	Normal	3	11	14	0.6	0	0
59	Normal	Normal	7	100	8	8	0	0
142	Normal	Normal	9	2	6	3	0	0

[a] Aschehoug (1952).

[b] Packed in cans with spiced sauce with preservatives.

TABLE VI[a]

CHEMICAL ANALYSES OF SPICE-CURED WINTER HERRING—SERIES 1

Days of curing at 12–15°C.	pH		Total volatile bases (mg. N/100 g.)		Total amino acids (mg./100 g.)		Total sugar (g./100 g.)		Invert sugar (g./100 g.)		Salt (g./100 g.)	
	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine
0	6.54	—	16.8	—	81	—	0	—	0	—	0	—
5	6.42	5.84	54.5	18.2	120	65	0.6	11.2	0.1	0.7	6.1	17.3
21	6.38	6.30	75.6	89.7	143	117	3.6	6.8	0.6	1.5	8.4	11.9
69	6.35	6.74	111	138	178	219	4.5	6.0	2.0	3.0	9.4	12.0
98	6.5	5.7	130	171	250	285	4.6	5.0	2.4	3.3	9.4	12.0
154	4.96	4.70	167	179	332	367	3.4	4.1	3.1	4.1	10.4	12.4

[a] Aschehoug (1952).

TABLE VII[a]

CHEMICAL ANALYSES OF SPICE-CURED WINTER HERRING—SERIES 2

Days of curing at 12–15°C	pH		Total volatile bases (mg. N/100 g.)		Total amino acids (mg./100 g.)		Total sugar (g./100 g.)		Invert sugar (g./100 g.)		Salt (g./100 g.)	
	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine
0	5.68	—	14	—	80.4	—	0	—	0	—	0	—
5	5.84	5.00	36.4	16.8	120	66	1.3	11.2	0.8	1.2	6.1	20.7
21	5.86	5.65	51.8	64.5	162	132	3.6	7.1	0.5	1.9	8.3	11.5
69	5.60	5.64	69	92	238	265	4.9	6.4	2.1	3.5	9.5	12.0
154	5.52	5.52	97	110	345	394	3.7	6.2	3.6	6.1	10.6	12.4

[a] Aschehoug (1952).

TABLE VIII[a]

CHEMICAL ANALYSES OF GAFFELBITAR OF CURED WINTER HERRING FROM SERIES 2[b]

Days of storage at 22°C.	pH		Total volatile bases (mg. N/100 g.)		Total amino acids (mg./100 g.)		Total sugar (g./100 g.)		Invert sugar (g./100 g.)		Salt (g./100 g.)	
	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine
7	5.03	5.03	67	77	217	256	12.6	15.7	2.2	2.4	7.1	8.5
35	4.89	4.90	78	91	308	344	12.3	12.6	1.0	1.4	7.6	10.1
142	4.90	4.93	98	110	485	580	11.8	13.8	3.2	3.9	7.3	8.3

[a] Aschehoug (1952).

[b] Packed in cans with spiced sauce without preservatives.

TABLE IX[a]

CHEMICAL ANALYSES OF GAFFELBITAR OF CURED WINTER HERRING FROM SERIES 2[b]

Days of storage at 22°C.	pH		Total volatile bases (mg. N/100 g.)		Total amino acids (mg./100 g.)		Total sugar (g./100 g.)		Invert sugar (g./100 g.)		Salt (g./100 g.)	
	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine	Herring	Brine
7	5.03	5.03	69	84	207	245	12.3	17.0	1.9	2.4	7.2	8.5
35	5.04	5.05	70	90	279	327	11.4	16.0	2.0	2.7	6.4	8.3
142	5.15	5.17	103	122	450	576	11.7	14.7	3.5	4.3	7.4	8.5

[a] Aschehoug (1952).

[b] Packed in cans with spiced sauce with preservatives.

teria from cured herring, which produce acetylmethylcarbinol on sugar-containing media.

In experiments with antibiotics (chlortetracycline), by treatment of sprats with formaldehyde or through γ-radiation of the packs, an effort was made to establish the true significance of bacteria in the maturing process of anchovies (Alm, 1958). It was shown that the intestinal enzymes are fundamental to proteolysis, the influence of bacteria being seemingly minor. Nevertheless, it is conceivable that bacteria are involved in the formation of aromatic substances, but definite proof has not been obtained. These experiments are being pursued. Truscott and Hoagland (1955) concluded that in vinegar-cured herring the intestinal enzymes are by far the most potent source of proteolytic activity.

A. MICROBIAL ASPECTS

The real function of the added sugars in these preserved fish products is not fully clarified. In low concentration they may even be germicidal. At high concentration they act unfavorably due to their osmotic effect. These relationships deserve closer study. In some cases a formation of lactic acid can be noted, decreasing the pH (Christiansen, 1962).

In Soviet investigations with sprats the interesting observation was made that sucrose at 0.1% prevented swelling by gas-forming inoculants of the genus *Aerobacter aerogenes*, but not at concentrations of 1–1.5%, but again at 3–5% (Levieva and Ivanova, 1960). Another pertinent finding is the observation that sucrose acts to suppress bacterial growth only at certain stages in the proteolysis of cured sprats in cans, but at a later stage accelerates the formation of lactic acid (Chernogotsev, 1960).

If salt-resistant bacteria are present, which in most cases is true, their growth could be facilitated by the nitrogenous substances becoming available through proteolysis. This is particularly pertinent when the cans are kept at high temperatures, allowing general development of microorganisms. Such growth of haloduric or halophilic strains has been reported in studies on cured sprats in cans (Ivanova, 1958).

V. Fermented Herring (Surströmming)

Fermented herring (*surströmming*) is specific to the northern Baltic coast of Sweden. It is a result of bacterial fermentation. Similar products exist from other fish, such as fermented trout—the Norwegian *rakørret* (Schmidt-Nielsen and Bohmer, 1935)—and also perch and gwyniad.

The raw material is Baltic herring, *Clupea harengus* var. *membras*, caught just prior to spawning from May 1 until the first week of July. The fat content of the herring is rather low at this time. In the autumn it is too fatty for this purpose. The herring, which must be freshly caught, is first treated in saturated brine for 30–40 hours with continuous stirring for the first 4 hours. After this pretreatment—the brine concentration has been reduced to about 9° Bé—the herring is eviscerated, but roe and milt are retained. The herring is packed in 60-liter barrels: 57 kg. herring and freshly made brine of 17° Bé. A head space of 1.5 inches is allowed in the barrels. After sealing, the barrels are rotated now and then for the first 3 days and then put into storage.

Fermentation starts in the middle of July and terminates after 2 weeks. This process is accompanied by vigorous formation of gases which escape from between the barrel staves. When the fermentation is ended, the herring is transferred to cans together with brine from the fermentation barrels.

Mörner (1895) has investigated this fermentation. The gases formed are carbon dioxide and hydrogen sulfide, the latter giving a very sharp odor when the cans are opened. This disappears, however, rather soon after opening. The characteristic odor of this herring comes from methyl mercaptan, which of course has a very strange odor but not as unpleasant as hydrogen sulfide. Neither indole, skatole, putrescine, nor cadaverine is formed.

Some people consider fermented herring a delicacy, others find it repulsive.

VI. Overripeness and Fermentation

As pointed out earlier, the maturing process in anchovies and tidbits is of a continuing nature and is not suppressed at any one point. In mature anchovy the brine has a rather strong protein-decomposing activity. The rate of degradation is influenced by temperature and it is possible to slow down this process through refrigeration. Higher temperatures may occasionally bring about complete dissolution of the herring flesh, leaving only a liquid. This liquefaction proceeds very rapidly, in particular at temperatures above 30°C.

Refrigeration is also necessary for other reasons. The finished products easily undergo fermentation by bacteria, even if preservatives are added. The bacteria in question are halophiles of a lactic acid-forming type. They form gas, and swelling of the cans does not necessarily mean that the products are less wholesome. Some experts even claim that an "anchovy" pack does not reach its full flavor until fermentation has started in the can. Fermentation is, however, not desirable from the point of view of food hygiene, and these products therefore have to be kept under refrigeration to prevent overripeness and fermentation.

Another type of bacterial attack on these products gives rise to the so-called ropy brine. This often appears in the barrels during the maturing process. The brine becomes quite thick and slimy. This phenomenon appears sporadically in certain years, but the conditions under which it occurs are not well understood. Its appearance is therefore rather unpredictable.

The sliminess is caused by certain bacteria (Lindeberg, 1954, 1957). *Achromobacter* strains isolated from this type of slime were cultivated on sucrose-containing media. They formed levan from the fructose (levulose) of the sucrose. The slime-forming substance in herring brine is also levan. This compound could be synthesized by these bacteria only from sucrose (and raffinose). Strangely enough these bacteria do not use sugars for growth, while amino acids and pyruvic acid together with other intermediates of the Krebs cycle are readily oxidized (Lindeberg, 1957).

This ropy brine inflicts large losses on the herring packing industry. Hjort-Hansen (1954) has been successful in preventing ropy brine by adding mustard to the barrels. Lindeberg (1957) suggested other methods which appeared feasible in order to check slime formation. He proved that sugars other than sucrose have an inhibiting effect on the bacterial formation of levan. A comparatively small addition of lactose suppressed the slime formation on laboratory media. A drastic method is, of course, to use dextrose as a substitute for sucrose and in this way make levan formation impossible. Dextrose is, however, more expensive, at least in dry form. The use of these methods does not appear to be economically feasible.

VII. Discolorations

Herring products have a strong corrosive action on tin plate owing to their content of TMAO (trimethylamine oxide), which is reduced by the metal to TMA thereby dissolving the tin and iron. This results in black discoloration through formation of iron sulfides, and in off-flavors. With the use of lacquered tin plate in cans and boxes, these risks have been removed.

A more difficult problem is the appearance of white precipitates on products of this kind. Wille (1931) showed these white coatings to consist of tyrosine. This was confirmed independently by Cultrera (1934). The amino acid is released during and after the ripening process. Being a less soluble substance, it forms white specks or patches on the surface of anchovies and tidbits. This phenomenon obviously constitutes no hazard but the product loses its finish and becomes less appetizing to the uninitiated. There seem to be no dependable methods known for preventing this, except cold storage of the product and early removal of the active viscera in the gutting and washing in order to reduce the rate of proteolysis (Truscott and Hoagland, 1955). Such white precipitates of tyrosine, so-called "flecking," are also described in aging hams (Hunt *et al.*, 1939).

VIII. Nutritive Aspects

Anchovies and tidbits do not belong to the basic foods. They are not consumed in large quantities. Fermented herring formerly made a certain contribution to the foods of the northern part of Sweden, but this is no longer so. The inclusion of these products in the menu as *hors d'oeuvres* appears to be well justified. They not only have an appetizing effect, but are readily digested. Their abundant content of free amino acids makes them an effective amino acid supplement to a cereal diet.

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CHAPTER 7

The Processing of the Anchovy: *Engraulis encrasicholus* Linnaeus

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I. Gastronomic Characteristics and Types of Products

Genuine cured anchovies are prepared exclusively from the fish of the species *Engraulis encrasicholus* Linnaeus of the clupeid family, by a process of salting and fermentation. This process goes back to ancient times and is common all along the Mediterranean coast and the Atlantic coast from the Gulf of Biscay down to the Straits of Gibraltar.

It is not known which particular factors in the composition of the fish give the final product its distinctive flavor. Experience has, however, demonstrated that the same process applied to sardines *Clupea pilchardus* or to sprats *Clupea sprattus* does not yield a product of a comparable quality by far. As a consequence, in France sardines and sprats are not used for salting—unless under exceptional circumstances, e.g., during the war when salting was almost the only available method for preserving fish.

Cured anchovies are sold on the retail market in the salted state, in 1/2- and 1-kg. containers, usually tin plate cans; in this case the consumer does the desalting and filleting, and usually lays the fillets overnight in oil. More often, however, the preparation is done in factories, and the fillets, either plain or each one rolled around a caper, are packed in small cans in oil, generally olive oil.

Anchovies are also ground to give anchovy paste, which, mixed with oil or butter, is sold in aluminum tubes or small jars under the names "anchovy cream" and "anchovy butter."

II. Salting

The best anchovies for curing should be of a size corresponding to 35 to 40 fish per kilogram (16–18 fish per pound), and as fat as possible, which depends on the season.

As soon as they are brought to the factories from the fishing grounds, which are not far from the shores, the fish, when not beheaded and gutted immediately, are sprinkled with salt and placed in concrete vats or large wooden casks, and may be kept 2–3 days under these conditions.

It is, however, preferable to treat them as soon as they are landed.

If presalted, the anchovies are first rinsed with saturated brine. They are then beheaded and gutted, an operation done by hand by just breaking and pulling off the head, at which most of the entrails follow. No particular care is needed, and the operation is much easier and speedier than in the case of the sardines. Beheading results in a loss in weight of about 30%.

A layer of salt about 5 mm. (3/16 in.) thick is put at the bottom of the container; a layer of fish, arranged parallel to each other, is put over it, then a layer of salt, another layer of fish placed at right angles to the preceding ones, a layer of salt, and so on. A final layer of salt comes on top, and over it a wooden disk charged with weights (large stones or blocks of concrete) to keep the fish well pressed. It is estimated that this requires weights of about 5–6 kg. (11–13 lb.) per 10 kg. (22 lb.) of anchovies.

Two or three days later the fish will have sunk considerably; the top layer of salt is then removed, more fish added with fresh salt, and the pile again weighed down. Sometimes the weights are increased gradually, but there are no precise rules for this, and it is not known how much compression is necessary. The essential point is to expel all air bubbles and to avoid the access of air.

The containers used are wooden barrels with a capacity of 50, 100, or 200 kg. (110, 220, or 440 lb.), and also hot-dipped tin-plate cans, plain on the inside and generally lacquered on the outside, holding 20 kg. (44 lb.). Smaller cans, as a rule, are not used for curing, but only for packing and shipping the already cured anchovies.

It is considered very important that the salt be at least 99% pure, and particular virtues are attributed to salts of certain origins; no experimental research appears ever to have been carried out in these respects. No mention is made by practitioners of the bacteriological purity of the salt, although it may well be important for the subsequent keeping of the filleted fish, if not for the curing process itself.

III. Curing

Water and fat are pressed out of the fish and form on top of it a layer of brine, covered with fat. This liquid overflows and is collected and subsequently used to spray over the anchovies during the cure. This spraying is done regularly in order to maintain the level of the liquid layer above the fish, when the overflowing facilitates the elimination of fat, blood, and other organic matter brought out by the salting and the compression. Great importance is attached to the collection of this brine to which is attributed a great influence on the quality of the final product. If this brine is not available in sufficient quantity, then a fresh 25% brine is used.

The treatment is thus continued at room temperature, for at least 6–7 months, sometimes more, depending upon the actual temperature, until the odor, appearance, and taste show that the cure has reached the desired degree.

At this point the top layer of salt is removed, the uppermost layer of fish is rinsed with brine, fresh salt is added, and the container is closed and is ready for shipping.

Very little experimental work has been done on the curing of anchovies, and even less published; as a consequence, the process is carried out according to tradition, and most of what is known about it is empirical.

The main research work, to our knowledge, can be accredited to Charles Lepierre, of Instituto Portugués de Conservas de Peixe, followed up in recent years by J. Mercier Marques. It has been summed up in a report given at the 2nd International Congress on Canned Foods[1] and published in the papers of the Congress in French and in English.

Two important points result from Lepierre's work.

A. The curing process carried out in sterile containers and using sterile salt and new and sterile brine gives a product which is identical with the one obtained under standard conditions.

These findings upset the traditional belief that the use of old barrels and of old brine is indispensable to successful curing. As a consequence, it will be possible to insist on cleanliness where this is not sufficiently understood or practiced. This will definitely be to the advantage of the quality and uniformity of the finished product.

B. Too high a temperature, far from accelerating the curing, slows down the process and results in an unacceptable product.

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[1] Lepierre, Ch., and Mercier Marques, J. (1951). Studies on the production of anchovies at the Portuguese Institute for Fish Preservation. *Proc. 2nd Intern. Congr. Canned Foods, Paris, 1951,* 6 pp.

The optimum temperature for the curing process has not yet been determined, nor the upper and lower limits of temperature range. From what is known from practice, it would appear that 15–20°C. (59–68°F.) is probably the most favorable range.

Lepierre concluded, at the end of his work, that no bacteria took part in the curing process, and that it was exclusively enzymic. Mercier Marques has definitely confirmed this conclusion; by following the increase of soluble nitrogen in the brine at various pH's, he has found that a pH of about 7.0 is the most favorable; furthermore, while malt extract or pepsin do not influence the curing, trypsin at pH 7.0 has a very marked accelerating effect: a perfectly cured product of very good quality could be obtained in 4 months by adding trypsin whereas the controls required 12 months. Research along these lines has been continued by J. Mercier Marques.[2]

Curing anchovies under almost sterile conditions may also improve the keeping quality of the fillets packed in oil. Due to the fact that the latter are partly desalted, they are apt to support the growth of certain halophilic bacteria and may sometimes spoil.

IV. Packing

A. Whole, Salted

When the curing process is ended, as judged by the appearance and the flavor, the product has to be stored in a cool place, or the breakdown of the fish proteins will proceed too far and end in total liquefaction of the anchovies.

In most cases, salted anchovies are stored and shipped in the containers, barrels or large cans, in which they have been cured. Only a small proportion is repacked as such in smaller containers—mostly 1/2-kg. or 1-kg. cans, but also earthenware jugs and glass jars—for the retail market.

B. Fillets in Oil

Cured anchovies, as such, need to be desalted and filleted before eating, and while this operation is still practiced in restaurants, the home consumer generally prefers to purchase the product ready for the table.

This final preparation takes place to a certain extent in some of the factories where the salting and curing have been performed; in most cases, however, separate establishments specialize either in the salting and curing or in the packing as fillets in oil, generally olive.

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[2] Mercier Marques, J. (1959). Le procédé industriel de l'anchoitage. *Rept. Intern. Permanent Comm. Canned Foods, Lisbon, 1959*, 7 pp.

Desalting and filleting are done entirely by hand, and are a costly operation because of the labor involved.

1. The cured anchovies are given a rapid washing, of about 15 seconds, in a more or less concentrated brine. The tendency is to use a brine of as low concentration as is compatible with the keeping quality of the final product; and this depends of course on the subsequent marketing, whether for rapid consumption in cool climates and nearby markets, or for shipping to large distances and for distribution in warm countries. Anchovy fillets of lower salt content are preferred, but will not keep long.

2. After rinsing, the entrails are removed, starting from the collar, with a finger, and without opening up the belly.

3. The skin is then rubbed off with the help of a coarse cotton cloth.

4. The next operation consists in trimming the tail fin, with scissors.

5. The fish is now ready for filleting: (a) the anchovy is opened up along the middle of the back; (b) one fillet is removed, trimmed and cleaned by scraping lightly with a knife; (c) the backbone, which is on the other fillet, is broken in the middle, and removed in two parts; (d) the second fillet is then handled as the first one; (e) the individual fillets are laid, inside up, on a clean and dry towel or on blotting paper.

6. A second towel is laid on the fillets, and pressed lightly upon them either by hand or with a rolling pin. This step has been improved in some Spanish factories by the use of a small centrifuge, in which the "sandwiches" of anchovy fillets between cotton cloths are placed vertically all around the rotating basket. The elimination of moisture is thus accelerated.

7. The fillets are finally packed in cans, in which some oil has previously been put. The fillets are carefully laid in successive layers, and the whole is covered with oil, usually olive. Plain cans are generally used, but some packers prefer inside-lacquered ones. After closing, the cans are not given any heat treatment.

C. Appetizers and Other Preparations

The anchovies are filleted as above, and each fillet is rolled around a cured olive, a caper, or some other vinegar-pickled vegetable; the rolls are then put into the cans and covered with oil. Lacquered cans are preferred.

Fillets of anchovies, flat or rolled, are also prepared in "sauce piquante," a spiced sauce containing oil, vinegar, and mustard.

Furthermore, the following pasty products, usually packed in soft aluminum tubes, are on the market:

(a) "pâte d'anchois" (anchovy paste), with a minimum content of 90% anchovies;

(b) "crème d'anchois" (anchovy cream), made with at least 75% anchovies and 10% oil;

(c) "beurre d'anchois" (anchovy butter), made with at least 75% anchovies and 10% butter.

V. Warehousing

Anchovies, whether in salt as cured or as fillets in oil, are what is termed a semi-preserve (in French, "semi-conserve") and will not keep long unless stored cool.

One type of spoilage is unavoidable even at low temperatures: it results from the enzymic processes, which go on and may end in complete digestion of the flesh proteins. Cool storage slows it down, however, and is in effect the only method which makes it possible to increase the keeping period.

Bacterial spoilage occurs, too, not in the salted cured stock, but in fillets in oil or similar preparations. It is erratic, and depends, as may be expected, upon the initial contamination of the fish, upon the sanitary conditions of the factory, and the degree of desalting.

Experimental investigations carried out in the author's laboratory indicate that desalting should go hand in hand with a certain degree of drying, so that the water remaining in the tissues of the fish may always be saturated with salt. Excessive removal of water, however, will result in a tough texture—and does not preclude the necessity of cool storage, unless a preservative is used. This is not permitted in all countries, e.g., in France.

VI. Regulations

French regulations concerning canned marine products are issued at two levels (see also Volume IV, Chapter 5): general rules are embodied in decrees and "arrètés," issued under the authority of the Ministry of Agriculture by the Service de la Répression des Fraudes (corresponding to the U.S. Food and Drug Administration), and more detailed definitions and specifications are given by "décisions" of the Confédération des Industries de Traitement des Produits des Pèches Maritimes.

The general definition of "semi-conserves" (semi-preserves) is contained in the decree of February 10, 1955.

Decisions Nos. 60 and 61 of the Confédération des Industries de Traitement des Produits des Pèches Maritimes give more detailed rules relating to the preparation and labeling of "semi-conserves" of fish, and particularly of anchovies.

Regarding the latter, it is stated that anchovy fillets in oil shall show a drained weight of at least 75% when packed flat, and 70% when rolled; the net weight for any single can shall not be less than 96% of the weight stated on the label.

All containers shall bear the words "semi-conserve" and "à tenir au frais" (to be kept cool) in type not less than 4 mm. (0.16 in.) high, as well as the name or identification number of the factory and the date of packing. Guaranty of good preservation is limited to 6 months.

Like all other canned fish products, canned anchovies intended for export are submitted to a special inspection, and cannot be shipped unless they have obtained a "certificat de contrôle à l'exportation" (export inspection certificate).

Closely related regulations are applied in other anchovy-producing countries, principally Yugoslavia and Italy.

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CHAPTER 8

Fermented and Dried Seafood Products in Southeast Asia

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I. Introduction

Millions of people living in Southeast Asia have remarkably low amounts of total protein in their diet, particularly compared with standards commonly accepted in North America and Western Europe. The animal protein content is even lower.

One of the most important sources of such protein in Southeast Asia is fish, both salt and fresh-water varieties. Fish, either fresh, dried, or salted or in the form of paste or sauce, is a common ingredient in the diet of the rice-eater. Nevertheless, the relatively high price of fresh fish and the limited supply of fish products, as well as their poor keeping quality together with inadequate marketing systems, have all hindered a larger consumption. Even along the coastal areas and the numerous rivers and lakes as well as in the neighborhood of fish ponds, consumption frequently is lower than would be expected. This is partly due to lack of efficient fishing equipment and to unsatisfactory methods of preservation.

Since World War II many governments in Southeast Asia have been endeavoring to expand fish production for local consumption. In general, however, the increases have been just about enough to keep pace with population growth. Exceptions are Japan and the Philippines, where an increase in per capita consumption has resulted. Such augmented fish production would of course be of limited value unless reliable methods of preservation were adopted at the same time, so that supplies could be made available to the large portion of the population living beyond the fish centers.

Canning, freezing, and icing, which are simple and relatively cheap methods of preserving fish in Europe and North America, are generally too expensive in Southeast Asia. Even very cheap Japanese canned fish products, available in the area prior to World War II, were usually too costly for the great majority of the population.

Tastes and dietary habits of the rice-eater differ from those of the American or European and require consideration. The Southeast Asian diet is usually monotonous and dominated by rice. Fish pastes and fish sauces with curries and Spanish peppers are much in favor. Drying, salting, and the making into pastes and sauces are therefore the most common ways of preserving fish in these (van Veen, 1953) and other underdeveloped countries. Fish in these forms are, however, subject to the action of numerous microorganisms. These may come from the entrails, the gills, and the slime of the fish, or be introduced with salt, air, etc. Many food products of high nutritive value prepared in this area, and subjected intentionally or otherwise to the action of bacteria, yeasts, or fungi, would be called spoiled or even decomposed in the West. They should, however, rather be compared with fermented foods such as cheese, sauerkraut, and yoghurt, which are equally rarely found to cause food poisonings.

The quality of many of the fish products under discussion is influenced not only by the method of preservation and the kinds of microorganisms present, but also by such factors as the nutritional condition of the fish (fat content, etc.), the activity of the enzymes in the tissues (autolysis), and the impurities present in the salt. In this connection, it may be useful to remember the part of the texture and taste of pickled herring in the Netherlands is attributable to the enzymes originally present in the fish pylorus, which is retained during the gutting operation (Liebert, 1924).

By following more or less fixed techniques (simple as these may be) over a period of many years, a fairly standardized product can be obtained. Alterations in texture, appearance, or flavor caused by microorganisms or by tissue enzymes are kept within uniform bounds. Fish products so treated develop uniform characteristics during ripening, which appeal to consumers accustomed to them.

The author found, when working on certain food products prepared in Java with the aid of certain fungi, that the microbial flora in and around the place of manufacture consists mainly of the fungi used in the preparation. The same is probably true with regard to the bacterial flora in many small plants in the Far East where, over the years, fish has been salted and prepared in the same way with ingredients of the same origin.

A number of these indigenous methods of fish preservation in the Far East will be reviewed. Of those described, many are more or less standardized for a given village or region. However, many minor or even major modifications are used in other places in the same area. A few examples will be given, indicating how these relatively simple methods of fish preservation offer a number of possibilities for further research, the results of which should enable the existing cheap methods to be improved. However, the acceptability of the products from the point of view of the rice-eater must always be kept in mind.

Consideration will be given to (1) fish sauces; (2) fish pastes; (3) salted fish not (or partially) dried; (4) dried, or salted and dried, fish products; and (5) miscellaneous products. The salted and partially dried fish and the fish sauces have been studied more extensively than the other products. The rather primitive methods of manufacturing fish meal and oil and smoked fish are not discussed because of their limited local importance.

II. Fish Sauces

A number of fish sauces are well known in Southeast Asia. Some of them are extremely popular in Thailand, Cambodia, and Vietnam, but scarcely known in Indonesia and practically unknown in India. A very good review of the literature concerning the investigations of the numerous fish products in former Indochina has been given by Westenberg (1941). It seems probable that fish sauces first came into use in regions where the climate is too rainy to allow sun-drying of the fish and where sufficient fuel cannot be found for artificial drying.

Fish sauces are limited in nutritive importance, due to their high salt content which is a major hindrance to large intake. They contain mainly hydrolyzed protein and minerals (sodium chloride and calcium salts), and are therefore comparable to soy sauce. They contain sufficient calcium salts to be rather important sources of this mineral if eaten regularly and in sufficient quantity. They are used chiefly as condiments for flavoring rice dishes. In countries such as Vietnam, Cambodia, and Thailand, the fish sauce industry is a very important one.

Microbiological and other processes play an important role in the preparation of many fish products, such as pastes and undried salted products, but their most pronounced effects are noted in the fish sauces. One of these, "nuoc-mam," has been carefully studied by a number of investigators, and many of the findings concerning nuoc-mam may be to a certain extent applicable to other fish products of Southeast Asia.

Lafont (1955) has discussed the dietary role of the fish sauces in Southeast Asia as well as their methods of manufacture.

A. NUOC-MAM

The nuoc-mam produced in former Indochina is consumed almost entirely by the domestic trade, although exports formerly were made to Thailand and Malaya. It is not easy to determine the total annual production, but estimates range from 35,000 to 100,000 tons (Gruvel, 1925). In 1935 about 67,000 tons were produced (Bouvier and Autret, 1944). The economic status of nuoc-mam is evident from the amount of salt used: in the year 1925 in the province of Binh-Thuan, the total salt used was approximately 15,000 metric tons and from this about 40.6 million liters of nuoc-mam was manufactured (Guillerm, 1928). During World Wars I and II, nuoc-mam was concentrated, canned, and shipped to the Annamite troops in France (Rosé, 1919b,c; Bouvier and Autret, 1944).

Nuoc-mam is a clear brown liquid, rich in salt and soluble nitrogen compounds. It has a distinctive odor and flavor. It is produced along the coasts (Rosé, 1918a–d, 1919a–c; Brémond, 1919; Mesnard and Rosé, 1920; Gruvel, 1925; Guillerm, 1928). The most important production centers in Vietnam are in the province of Binh-Thuan (South Annam) and on the island of Phu Quoc. The best products have a rather strong cheese-like odor and salty taste. The cheaper products are unattractive and generally not liked by the Westerner. Nuoc-mam is usually prepared from different kinds of small sea fish, mainly species of clupeids and carangids such as *Decapterus*, *Engraulis*, *Dorosoma*, *Clupeodes*, *Stolephorus*, and others.

During and after the war the production of nuoc-mam from fresh-water fish increased greatly. Formerly this had a poor reputation due chiefly to deficient methods of manufacture. However, it does not seem to have quite the flavor of nuoc-mam prepared from sea fish. It is usually made of small noneviscerated fish. The possibilities for increasing the production of nuoc-mam from fresh-water fish in Cambodia are enormous (Lafont, 1950). Nuoc-mam can also be prepared from shrimp (Truong Tan Quon, 1951).

In the most primitive method of manufacture, small fish are first kneaded and pressed by hand, then salted and placed in earthenware pots that are tightly sealed and buried in the ground. They are left there for several months. When dug up and opened, the supernatant liquid that has formed is carefully decanted. This constitutes the nuoc-mam. In the commercial manufacture of nuoc-mam in South Annam, large vats with a bamboo tap fitted near the bottom are used (Rosé, 1918a; Gruvel, 1925).

The fresh uncleaned fish are mixed with salt and dumped into the vats. The amount of salt varies according to the kind of fish; usually 4–5 parts salt to 6 parts fish are used (Rosé, 1918a). For some species of fish proportionally more salt is added to the upper layers in the vat. The fish are piled above the top of the vat. A final layer of salt is placed on the pile of fish. After 3 days, the collected turbid and bloody liquid ("nuoc-boi") is drained off. A part of it is returned to the vat; another portion is saved and used later. On exposure to the air, the liquid becomes somewhat clearer (Guillerm, 1930). The fish settle below the top of the vat, and the layer of salt almost disappears. The fish are now packed down thoroughly. Some of the nuoc-boi is poured back over the fish until they are covered to a depth of about 10 cm. The contents are then covered with large bamboo wickerwork and heavily weighted.

The period of aging now begins and varies according to the kind of fish used (Rosé, 1918a). Only a few months are required to produce good nuoc-mam from small fish, but a year or even 18 months may be needed for large fish. Generally, the higher the concentration of salt (e.g., 200 g. per liter) the more the proteins are hydrolyzed into amino acids and other products of low molecular weight, and the better will be the keeping qualities of the nuoc-mam.

Originally, the nuoc-mam was allowed to stay in the same vat until ready for consumption; now, however, lixiviation is frequently practiced. After maturing, the pickle is run off through the tap; this is the first-quality nuoc-mam or "nuoc-nhut." A product of lower quality is then obtained by extracting the residual mass with boiling sea water. Here the liquor from the first vat is transferred slip-wise into a number of other vats, and the first vat is again suffused with sea water. This procedure is repeated several times (in a counter-current manner) in order to lixiviate the fish as thoroughly as possible. The several extracts are usually mixed together. This mixture constitutes nuoc-mam of lower quality, with much poorer keeping qualities. Before lixiviation, caramel, roasted rice, molasses, or corn (first boiled and then roasted) is sometimes added to the fish in order to darken the color and give the product a certain flavor. These additives also improve the keeping properties of the poor-quality nuoc-mam (Rosé, 1918b; Guillerm, 1928), probably because they produce acids, such as butyric, which lower the pH (Vialard-Goudou, 1941, 1942).

The undissolved fish residuum, the so-called "xat-mam" or "nuoc-xat," is usually sold as a manure. If *Dorosoma nasus* Bloch or other fatty fish are used, oil comes to the top of the pickle during the ripening. This oil can be separated and sold.

The methods of manufacturing nuoc-mam may vary somewhat in other parts of the country. The basic principles are the same. They involve careful regulation of the enzymic degradation and extraction of the fish proteins and other substances under mild pressure and anaerobic conditions.

An improved and simplified method for the manufacture of nuoc-mam was reported by Ngo-Ba-Thanh (1963) which in essence represents a modification of the classic process.

One part fish gives 2–6 parts nuoc-mam, depending upon the nitrogen content of the end product. According to 1933 regulations, nuoc-mam must contain 15 g. nitrogen per liter in the south of former Indochina and 5 g. per liter in the north.

In Cambodia, according to Bouvier and Autret (1944), 1 liter first-quality nuoc-mam contains 15.85 g. total nitrogen (of which 11.15 g. is organic nitrogen and 5.0 g. amino nitrogen), 270 g. sodium chloride, and 0.5 g. CaO; in the north, 1 liter undiluted first-quality nuoc-mam contains 19.3 g. nitrogen (11.7 g. organic nitrogen and 8.7 g. amino nitrogen), 276 g. chloride, and 0.565 g. P_2O_5 (see also Nguyen-Xuan-Tho, 1952).

The poorer classes use about 4 times (60 ml.) the daily amount of nuoc-mam consumed by the wealthy (Nguyen-Thi-Lau and Richard, 1959). The former category in the same area eat about 20 g. daily of "mam-ca" and 30 g. daily of "ca-kho," two other fish preparations. Toury *et al.* (1958) found that nuoc-mam prepared at Dakar (Africa) was a good source of essential amino acids, especially lysine.

Because of the great importance of nuoc-mam, official methods of analysis were set up before the last war in former Indochina (Rosé, 1918a; Guillerm, 1928), mainly in connection with legal standards. These include tests for total nitrogen, organic nitrogen, amino nitrogen (Sorensen's formol), volatile nitrogen bases, salt content, and pH.

Hydrolysis of the fish proteins takes place under sterile conditions also (Mesnard and Rosé, 1920); peptides, amino acids, and ammonia are the resulting products. Therefore the enzymes in the fish (meat and entrails) appear to be as important as the microorganisms in bringing about protein hydrolysis. Glycerol extracts of the entrails are particularly active, even in the presence of salt.

Products made aseptically, however, lacked the typical nuoc-mam flavor and, when prepared on a semicommercial scale, were not acceptable (Krempf, 1924). This also appears to be true for fish meal prepared in former Indochina (Krempf, 1934). As a result, Krempf (1928–1929) occupied himself with the practical problem of producing the true aroma of these products.

Boez and Guillerm (1930a,b) isolated an anaerobic spore-bearing bacterial species from fish. It seems to be a new (as yet unidentified)

Clostridium and is said to produce the typical flavor of nuoc-mam. The organisms are strictly anaerobic, form gas, and show optimal growth between 28° and 45°C. (82.4° and 113°F.). Milk is coagulated and digested, egg protein is digested, and no PbS is formed from lead acetate, even after addition of hyposulfite. Glucose, maltose, fructose, and sucrose are fermented with the formation of gas. This organism also has strong proteolytic properties and seems to be the main producer of the volatile nitrogen bases from maturing nuoc-mam. On Veillon agar medium (15 g. glucose and 1 g. KNO_3 per liter) the characteristic nuoc-mam odor developed. Later these workers and also others in Indonesia and Thailand discovered many other bacteria which could produce the typical flavor. It is said that fish meal exposed to the action of these bacteria acquires the proper flavor and was acceptable to the population. The slow breakdown of the fish protein seems to be due to two causes: the fish enzymes and the enzymes from bacteria.

In this connection it is important to mention that in the western part of former Cochin China (Chevy, 1931–1932) the nuoc-mam is produced from eviscerated fish which, because of the lower content of proteolytic enzymes, go into solution very slowly. To hasten the process, fresh proteolytic pineapple juice is added. If nuoc-mam has a high pH (6.8–7.2), it cannot be kept for long (Guillerm, 1928).

Experiments were conducted in France (Gauducheau, 1928) on flavoring the meat of animals after slaughter by injection of nuoc-mam into the large veins; the results are said to have been favorable. This is said to have been done also with tuna fish by Japanese fishermen.

The author (unpublished) found that practically all the nitrogen compounds in nuoc-mam can be dialyzed, indicating that the protein is completely broken down. But nuoc-mam did not contain significant amounts of thiamine, riboflavin, or pyridoxine. It is therefore not a good source of the B vitamins.

Nuoc-mam has a high content of methyl ketones, which probably account for the cheese-like odor (van Veen, 1941c); diacetyl and methylacetyl carbinol are absent (van Veen, 1941c; Dang M-Kha, 1941); Autret and Vialard-Goudou (1939, 1940) have published data on the amino acids in nuoc-mam, and Vialard-Goudou (1941, 1942) on the volatile bases and acids. Histamine was found by Cousin and Noyer (1944).

Other fish sauces are manufactured in former Indochina and elsewhere in Southeast Asia; however, they are less interesting than nuoc-mam, and fewer studies have been done on them. There is also a kind of sauce called "nuoc-mam ruoc" which is prepared from shrimps along the coast of Thailand and differs in flavor from the ordinary nuoc-mam (Chevy, 1929). Boury (1952) states that nuoc-mam can also be manufactured from a good grade of ordinary fish meal. This has been tried in other places in Southeast Asia, but in general these products lack the cheese-like flavor of a good nuoc-mam.

B. Other Types

Fish sauces are common in the Philippines (Martin and Sulit, 1955). They are usually prepared by fermenting sardines, anchovies, ambassids, and shrimps (*Atya* sp.). The method of manufacture is somewhat similar to that for nuoc-mam; although less complicated, it requires considerable time (Division of Fisheries, Manila, 1946). "Patis" is a by-product of the manufacture of "bagoong" made from shrimps by draining off the liquid obtained in the fermentation and boiling it (Miller *et al.*, 1946).

In Thailand, fish sauces are called "nam-pla." They are made preferably from *Stolephorus*, but also from small *Scomber* and certain clupeids. The manufacture is similar to that for nuoc-mam but usually somewhat simpler. The process takes about 6 months, but for better qualities 2–3 years may be required. Approximately 1 liter is produced from 1 kg. fish. As in former Indochina, the product is sometimes made from fresh-water fish (see also Velankar, 1952).

In a number of places in Southeast Asia, the liquors obtained from salting fish in different ways are cooked and concentrated (for example: "tuk-trey" in Cambodia and "petis" in Indonesia). These products are usually inferior to the fish sauces that have been mentioned. The nitrogen:salt ratio is rather low.

Shimo (1951) describes a product from Japan called "shotturn" that is used for the same purposes as soy sauce and prepared from sardines, cuttle fish, herring, or fish waste materials. Fukuda (1955) recommends the use of antioxidants to prevent rancidity of "shiokara," a product prepared by autolysis from fish guts, livers, etc., which seems to deteriorate easily.

III. Fish Pastes

Fish pastes are eaten almost everywhere in Southeast Asia, generally as a condiment for rice dishes. Sometimes carbohydrates (roasted cereals, glutinous rice, flour, and bran) are added in varying amounts to the pastes. In this case the expression "fermented fish" is applied. The absolute amounts of these products consumed in the diet are small, although on the basis of their nitrogen content they are eaten in greater quantities than the fish sauces.

The method followed in the Philippines for preparing the fish paste, bagoong, is as follows. From January to May large quantities of sea fish, anchovies, and ambassids are available and are caught for conversion to paste. A species of small shrimp (*Atya* sp.), "alamang," is also used. The fish are first cleaned and uniformly mixed with coarse-grained salt in the proportion of 1 part salt to 3 parts fish, then put into clay vats to mature until ready for consumption, either raw or cooked. In bagoong, most of the protein breakdown is done by the fish enzymes and not by bacterial enzymes (Uyenco *et al.*, 1953). The resulting product is of a pasty consistency but very palatable. Sometimes it is colored by adding "ankak" —a fermented rice product, reddish from a wood dye (Miller *et al.*, 1946).

Hamm and Clague (1950) recommend that bagoong be prepared with only the amount of salt that will saturate the moisture in the fish. The moisture content varies, but most of the commonly used fish contain about 80%. One part of salt (with 99% or more NaCl) to 3.5 parts by weight of fish yields a product with but slight excess of salt. These workers indicate that pure salt should be used, since digestion is more rapid and fewer difficulties are experienced with halophilic bacteria.

Hamm and Clague also observed that bagoong manufacture can be accelerated by storing at 45°C. during manufacture. Martin and Sulit (1953) have shown that dried "dilis" can be used for the preparation of bagoong. Hermetically sealed tin containers are preferable for aging, although large deep containers may be used.

Sulit and Santiago (1949) report that, according to the Philippine Pure Food and Drug Law, bagoong should contain 40% solids, 12.5% protein, 20–25% sodium chloride. Martin and Sulit (1955) give extensive information not only on bagoong but also on the fish sauce, patis. They mention that a good grade bagoong has a cheese-like odor.

Many kinds of fish paste are manufactured in Southeast Asia by methods that are often rather complicated. The fish paste of Cambodia is called "prahoc." At least two methods of preparation are employed. In the first, cyprinids are used (e.g., *Rasbora* sp. and *Thynnichtys* sp.); in the second, *Ophiocephalus* sp. and others are used. Descriptions of the first method are given by Brémond (1919) and Le Poulain (1938). The fish are beheaded and eviscerated and put into a wicker basket without being scaled. The heads are either thrown away or may be preserved for the manufacture of oil. The fish, which half fill the basket, are trampled by foot to remove scales and press out entrails. The fish are washed in a river or pond, then stirred by hand until the scales are completely removed. They are again pressed in order to remove water. The upper part of the basket is covered with banana leaves and weighted with stones for about 24 hours.

The following day the fish are mixed with coarse salt for about half an hour, and then spread out on matting in the sun for a day. The salted and dried fish are returned to the basket for packing.

The next phase, pounding small quantities of the fish in a wooden mortar for about 20 minutes, takes place in the homes of villagers, and it is salted to taste. The paste is then placed in open earthen jars in the sun. During the evening the jars are covered to keep out insects. Fermentation or ripening now takes place, and a pickle gradually appears on top of the paste, which is removed every day. The Cambodians use this as nuoc-mam. This phase of the process may last a month. When no further pickle forms, the prahoc is finished and is ready for immediate consumption. It is used principally in the preparation of soups, which play an important role in the Cambodian diet.

Three parts of fish produce one part of prahoc. In many cases, the paste during the ripening is kept out of contact with air by carefully closing the containers. According to Chevey (1930–1931), autolytic enzymes are not very important in this process since the entrails have been removed. Bacterial activity appears to be mainly responsible for the characteristic properties of prahoc. However, a paste can be made out of the washed and salted entrails together with fresh fish meat. Roe may also be used.

In Cambodia, Vietnam, and Laos, fish pastes are also prepared with addition of cooked glutinous rice, roasted rice, rice bran, and other cereal products. "Padec" is a fish paste from Laos made with salt and rice bran.

In Cambodia, salted fish with heads and entrails removed are kneaded with glutinous rice pretreated with a native yeast preparation. This is called "phaâk" or "mam-chao." In other parts, small salted fish are treated with roasted rice, or roasted rice and sugar, and kept under pressure in containers. This product is called "mam-cu-sak" and may be mixed with unripe papaya or pineapple to accelerate the ripening, or with ginger in order to obtain a special flavor. It is said that these products can be kept for years if the containers are kept closed. Nothing is known of their chemical composition.

Some work has been done on the chemical composition of fish pastes (Brémond and Rosé, 1919). They consist of a soluble part (mineral salts, protein cleavage products, ammonia, etc.) which is somewhat comparable to nuoc-mam, and the insoluble unfermented fish. The moisture content of the samples investigated was 52–63%, and the soluble part 26–30%. Soluble nitrogen is usually less (in a few products much less) than 50% of the total nitrogen. The digestion process is therefore far from complete.

According to Bouvier and Autret (1944), prahoc contains 37.8 g.

nitrogen per liter of which 22.4 g. is soluble, with 17.9 g. organic nitrogen of which 4.3 g. is amino nitrogen. According to the same authors, padec contains about 17–27 g. nitrogen per liter. "Mam-tom," a paste made from shrimps, contains 21–23 g. (see also Lafont, 1951).

In Thailand, pastes are made from shrimps, preferably small ones, as well as from small fish. The fish are said to give a product of poorer quality. Sometimes various forms of carbohydrate and dyestuffs are added.

In Indonesia, especially on Sumatra, a fish paste called "trassi" is manufactured in large quantities and exported to Java. It can be made from fish as well as from shrimps. The method of manufacture is different from that used in the Philippines and former Indochina; the paste is not put into containers but is exposed to the sun in thin layers. "Trassi udang" (Markus, 1929) is made from a type of plankton consisting of very small shrimps called rebon (*Schizopodes, Mysis,* etc.). The most important center for its manufacture is Bagan Si-api-api (Sumatra).

Aboard the fishing boats, the shrimps are mixed with about 10% salt. When the boats have returned to harbor, the rather ill-smelling mass is mixed after a few days with another 5% salt. After grading, the mass is spread out on large floors and exposed to air and sun for 1–3 days. The moisture content decreases from about 80 to 50%, and the very evil smell of the decomposing product, infected with fly larvae, grubs, etc., slowly disappears. The mass is then carefully mixed by kneading for about 15–20 minutes. It is further dried in the sun and kneaded again; at the same time red synthetic dyestuffs (for example, carthamine DD and rhodamine B) are added. The end product usually contains 50–75% moisture, 15–20% salt, and 27–30% solids (protein, Ca salts, etc.). On the average, 3 parts of shrimp give 2–2.5 parts of trassi. The product, a red-colored sticky mass, is often adulterated with starches, rice bran, potato peel, etc.

"Trassi ikan" (fish paste) is also manufactured, usually from small fish, in large quantities in Bagan Si-api-api. The fish are mixed with salt in the boats. When the boats reach harbor, the salted mass has often a very disagreeable smell. The mass is dried in thin layers in the sun as soon as possible, mixed with more salt, and pounded until a paste is obtained that will lose no more water in the hot tropical sun. Trassi ikan is usually mixed with dyestuffs to give it a more attractive appearance.

These trassi products usually have a strong smell, keep for a very long time, and are often mixed with Spanish peppers, etc., to give very spicy products called "sambal" that are used regularly in Indonesia with every rice meal together with dried and salted fish.

Trassi ikan usually contains 35–50% moisture, 20–45% protein and protein degradation products, 10–25% minerals (NaCl and Ca salts), and a small percentage of fatty substances.

Jansen *et al.* (1953) found "trassi" to have a high content of vitamin B_{12}.

Not much is known of the fish pastes from Burma, very popular in that country. U Chit Thoung (1941) describes three kinds of "nga ngapi" prepared from fish, often previously sun-dried. The average composition is: moisture content 40–50%, protein 20–30%, fat 3–5%. There is also a "ngapi seinsa" made from shrimp and prawns. Duchateau *et al.* (1953) analyzed the nonprotein amino acids of this product.

In general the raw material is dried in the sun for 3–4 days, pounded to a paste (sometimes very incomplete) with addition of salt (usually in a wooden mortar), and kept in jars for at least 3 months. Only "ngapi" made from big fish "ngapi gaung," is salted fresh. Very often these pastes still contain large chunks of the original fish.

It is unfortunate that so few studies have been done on fish pastes. Elimination of the entrails for the preparation of certain pastes, short or long exposure to the sun for others, and sometimes ripening under more or less anaerobic conditions seems to be important in producing their characteristics. The pastes can probably be best compared with products such as "pedah," which will be mentioned in the next section. Without doubt enzymic and microbial processes, as described for nuoc-mam, play an important role; however, they produce much less pronounced results than in the case of fish sauces.

IV. Salted Fish Not (or Partially) Dried

In Thailand, one of the most important sea fish, *Scomber neglectus* ("pla-thu"), and the closely related species, *Scomber kanagurta* ("pla-lang"), are salted and exported to Malaya and Indonesia. It is not known whether the salted pla-thu and pla-lang for export are treated more carefully or in any other way than the product consumed in Thailand itself. However, the product from Thailand is highly valued, especially in Indonesia, because of its good keeping qualities and its special flavor. In Java it is called "pedah Siam" and this name will be used. It is not known whether the results of the investigation also apply to the unexported product. The fresh fish is called "kembung" in Java.

The pedah Siam arrives in Indonesia in very large bamboo crates, in which it can be held for a number of months. Unpacked, the product can be kept for a few weeks or a couple of months at the most, depending on the quality. Because of its superior quality, the pedah Siam has been studied extensively in Indonesia, especially by the present author (van Veen, 1941,a,c). It was possible to prepare the product from local kembung (*Scomber* sp.) as well as from other species. The experimental work was halted by the outbreak of the war in the Far East in 1941.

The best pedah Siam ("merah basah," meaning, brown, wet, and soft) is a fatty, partly dried fish of a beautiful brown color, weighing about 40–70 g. Generally the fish is not cut open, since the entrails are removed, together with the gills, via the throat. Usually there is scarcely any salt left between the fish when they are unpacked after arrival in Indonesia, but sometimes a lot of salt mixed with exuded dark brown fat can be found. This salt is highly prized in Java and used for a number of purposes, including the manufacture of soy sauce. This extra salt is probably added to prevent spoilage, if the fish is not quite fresh when salted for the first time, or when washing and drying take too much time.

Cheaper qualities contain less fat and do not have so intense a brown color. The deep brown color and high fat content (7–14%) go together. The cheaper "white pedah" ("putih kering," meaning white and dry) is usually relatively poor in fat (2–7%) as well as rather dry. The brown fat pedah consists mainly of *Scomber neglectus* van Campen (a coastal variety), whereas the white lean pedah is prepared from *Scomber kanagurta* Russel (a deep-sea variety).

Not as much is known about the exact method of preparation in Thailand. The fish are salted, stored for 12–24 hours, and washed and dried very superficially. Sometimes more fresh salt is added, and the mixture is carefully packed in large crates in which it is submitted to a maturing or ripening process which takes a number of weeks or months. When the maturing is finished, the fish meat should have a more or less pasty consistency and a fresh red color. These are two of the factors for judging quality on the market. The pH of the meat should be 6.0–6.4; a pH of 6.5 or higher usually indicates a low keeping quality, as is true with nuoc-mam. We came to the conclusion in our investigations that careful packaging of the fish is very important; maturing under anaerobic conditions is a *sine qua non* for getting a high-quality product. Moreover, the liquid formed during this period should be allowed to drain away; otherwise, a sauce or paste will result.

The content of volatile nitrogen bases (ammonia and traces of mono-, di-, and especially trimethylamines) is usually very low; they therefore do not contribute to the peculiar flavor of the product. Only when the keeping quality is low and spoilage sets in as the pH rises to 6.8 or higher are considerable amounts of these products formed and liberated. The immature pedah has a rather strong fishy odor.

The content of volatile water-soluble fatty acids is low, and the content of volatile water-insoluble fatty acids is very low. The volatile fatty acids do not therefore contribute much to the peculiar flavor.

The brown color of the best qualities of pedah Siam is due to oxidation products of the body fat. The peculiar odor of the fish has been analyzed and found attributable partly to methyl ketones. There appeared to be a parallelism between market quality and methyl ketone content (measured by the salicylic acid condensation method according to Täufel *et al.*, 1937). After unpacking and exposure to the air, the intensity of the flavor and the amount of methyl ketones present increase considerably. This is especially true if the fish have been made into a paste. Furthermore, a relatively large quantity of butyl aldehyde can be isolated in the form of its 2,4-dinitrophenylhydrazone, i.e., 50 mg. crude product from 100 g. pedah (van Veen, 1941a, b, c and unpublished results). A third odoriferous substance was found to be a volatile, very unstable, unsaturated aldehyde of which no crystalline derivative could be prepared. Epihydrinaldehyde (Kreis test), diacetyl, or methylacetylcarbinol was not found. Traces of volatile fatty acids and nitrogenous substances contribute slightly to the pedah flavor.

It should be observed that pedah in its wholesale packing, with air excluded, is far more durable than when it is unpacked, exposed to air, and infected by new microorganisms such as putrefactive bacteria. In the tropical climate the quality of the unpacked pedah will gradually decrease until actual spoilage sets in.

A good quality of merah basah contains 44–47% moisture, 7–14% fat, 21–22% total protein (N × 6.25), and 15–17% NaCl; putih kering contains about the same amount of moisture, 2–7% fat, 26–37% protein, and 12–18% salt.

In the experiments in which we tried to manufacture pedah Siam, we started with the assumption that ripening is caused partly by autolytic enzymes and partly by invading microorganisms. We were able to isolate from pedah Siam a strain of non-spore-forming bacteria which was highly resistant to salt and able to live under both aerobic and anaerobic conditions. It was even possible to induce a pedah flavor in salted herring; later, however, this strain deteriorated owing to unfavorable circumstances (unpublished data). We tried a number of admixtures which are often used in these regions, such as rice bran, roasted rice flour, cane sugar, "ragi" (Javanese yeast preparation, containing rice flour), and also salt obtained from imported pedah Siam (perhaps containing the right sort of bacteria). As was mentioned, the salting usually took only 1 day but, when the product had to be transported a long distance, several days might be required.

In our own small-scale experiments, after washing with tap water and superficial drying in the sun, the fish were mixed with other substances and closely packed in large wide-mouth glass and earthenware jars, on top of which a few bricks were placed. Every couple of days the drip was drained off.

We also tried to make a pedah paste by either pounding or milling the fish at the beginning or at the end of the ripening process. Usually after 1–3 months a pedah flavor started to develop in the whole fish, as it did in the pastes. Texture, color, pH (6.5), methyl ketone content, and content of volatile nitrogen bases of the meat served as very useful guides.

Usually the fish were eviscerated; however, it might be possible that this is not necessary. The fresher the fish when salted and the shorter the time for washing and drying, the better the quality of the final product.

Good pedah could be prepared in this way not only from both *Scomber* species mentioned, but also from "lemuruh" (*Clupea leiogaster* C.V.) with 7.8% fat; and from selar (*Caranx* sp. div.) with 3.5% fat. In certain cases, salt from imported pedah and additions of cane sugar or roasted ragi gave very good results. They were, however, rather irregular, and probably the technique for using these additions could be considerably improved.

We also started experiments on making dry cakes either from local pedah (after pounding or milling) and pedah paste or from mixtures of these with roasted soybean flour, dry food yeast, etc., which seemed to offer great possibilities as far as keeping qualities and acceptability by the population are concerned.

It is much easier to prepare pedah from fat fish than from lean; however, there are probably still a number of technical and scientific problems the solution of which will facilitate the study and improvement of the maturing process. From a commercial point of view, pedah from fat fish is to be preferred to pedah from lean fish. For example, in one experiment pedah merah basah lost only 10% by drip, whereas putih kering lost 30%. Both, however, retain much more weight (water) than dried salted fish.

In the preparation of nuoc-mam the purpose is to get as much breakdown of the protein as possible by means of autolysis and bacterial enzymes. This can best be accomplished not only by leaving the entrails in the fish but also by keeping the fish submerged in the pickle. In the preparation of pedah Siam the aim is to retain as much fish as possible of the right flavor and texture. This is achieved by cleaning the fish and draining off as much as possible of the resulting pickle, which contains many bacteria and perhaps many dissolved enzymes. In both processes the best products are obtained under more or less anaerobic conditions.

A very important fish product in Indonesia is "pindang." The fish are put in pots or cans and cooked in water with an amount of salt, equal to 5–50% of the weight of the fish; sometimes spices and flour (tapioca) are added. At the end of the cooking process, the product is put in earthenware pots and covered with leaves, or in closed gasoline cans, in order to exclude air and prevent air-borne infections. The product can be kept for a few days only or for a few months, depending on the amount of salt used, before spoilage or rancidity begins in the tropical climate. The closed pots or cans are transported inland. Pindang-like products are known elsewhere in Southeast Asia.

It can easily be understood why a preparation like pindang, especially when prepared without much salt, causes serious fish poisoning (very severe gastroenteritis) in the tropics (Mertens, 1939). The microorganisms involved are not yet known.

In Ceylon, eviscerated fish with gills removed and washed in 10% saline solution were satisfactorily kept in saturated brine if a mere 2% of citric acid was added to control pathogenic microbes and to aid in the initial salt penetration (Gunasekera *et al.*, 1956).

A. SALTING AND DRYING

Ordinary drying, or salting and drying, are the least expensive and simplest methods of preserving fish. Such products are reasonably cheap to transport over long distances as compared with iced or canned fish, but of course do not keep as well in the hot damp tropical climate as in colder and/or drier regions. This is especially true if the salt used is very crude and hygroscopic. The only possible procedure then is to redry the fish frequently, which may have detrimental effects on the product as far as nutritive value, flavor, color, etc. are concerned. Preservation of either salted or unsalted fish by smoking, done in several countries such as former Indochina and the Philippines, is on a small scale. Reference will be made to a few of the more interesting methods.

Small fish and shrimps can be dried in the sun. In Sumatra, shrimps are cooked for a short time with water and a small amount of salt, sieved, dried in the sun for a couple of days, and thrashed to remove the shell.

Anchovia commersoniana Lacépède is the most common anchovy of the Philippine waters. It is usually dried and called "monamon" or "dilis" and made into bagoong (Miller *et al.*, 1946). Other species of anchovy are also used in this way. "Daing" refers to any kind of fish which has been salted and then dried. The dried salt-water shrimps "shiba" are a good source of protein (50%).

It is reported that fish are very often dried for home consumption without salting. In Indonesia small fish are dried in the sun with little or no salt. Somewhat larger fish are cut open, cleaned, and sun-dried.

In Cambodia, which has a dry climate for about 7 months of the year, cleaned fish are dried in large quantities.

In Malaya, "filis" (*Stolephorus* spp.) is usually found on the market and may be sold fresh, cooked, or dried; the last is the most common. Since dried filis contains about 45% protein, it is a good cheap protein source (Svasti, 1954).

B. Salted Products

There are numerous methods of salting fish. Fish can be treated with dry salt in small quantities, but this usually results in poor keeping quality. Larger amounts of salt, up to 50% and even 100% of the weight of the fish, may be used if this is economically possible. In other regions, fish are put in brine. The fish are salted after eviscerating, or in some cases the whole carcass is salted intact. In many places, the salt or brine is used twice. This might seem to be an economic measure only, but it may be important in securing the desired flavor. The action of bacteria contained in the once-used salt or brine may be responsible. In some areas the fish are in salt for only a couple of days, in other places up to several weeks or more. Dried, pickled and dried, or salted and dried fish usually does not keep longer than 2–3 months in Java.

In some regions the fish are cleaned and salted when fresh. However, it has been reported that in Cambodia the fish, with the heads removed, are put in fresh water for a period of 12–16 hours before salting. In this case, the fish become heavily infected and autolysis sets in. The growth of the infecting microorganisms is subsequently stopped by the added salt. It is said that this procedure gives the product a better taste and appearance.

The salting itself is done in several ways. The salt may be rubbed in the fish, or fish and salt may be placed in alternate layers. Usually, the salted fish are dried in the sun. It is reported that in Tonkin the salted fresh-water fish are first treated with roasted and pounded rice and then dried in the sun. Nothing is reported on the properties and keeping properties of this interesting product (Westenberg, 1941). Lafont (1950) described the manufacture of dried-salted, smoked, and fermented fish products in Cambodia (see also Lafont, 1952). Krishna Pillai *et al.* (1956) studied the chemical quality of fish products from the west coast of India that had been cured in different ways, such as sun-drying, dry and wet salting, and pit curing; Saha *et al.* (1949) analyzed some 15 varieties of sun-dried fish available in Bengal.

In Japan, "amino hoshi" is made by salting, boiling, and carefully dehydrating, and is a patented product. The salt content should not be less than 10%. It is said that this product has a high keeping quality.

In some of the islands in the South Pacific, fish meat is boiled over a slow fire with sea water and an equal amount of coconut milk until dry. It is stated that the resulting dried product has better taste and keeping quality than ordinary fish; this interesting product should be further investigated as to biological value of the protein and bacterial count (McKee, 1956).

From the foregoing it is clear that there are many ways in which fish are salted in the Far East. This is due partly to the fact that fish of different species and of varying size must be handled differently. Salt will penetrate small fish within a few hours, whereas large fish have first to be cut open and carefully cleaned before salting.

Price and quality of the salt are very important. If the price is very high, the fisherman will be inclined to use as little as possible and even try to use the salt a second time. Old habits also play a great role in the methods of salting. There is not much exchange of ideas and experience in this part of the world (outside the large cities), and the simple techniques of drying and salting are, for the most part, traditional.

A most peculiar method used by the Dyaks in central Borneo, near the Kapuas River, was reported to the Southeast Asia Fisheries Conference held in Singapore in 1947. The salted fish is partly dried and in a short time is heavily infested with fly larvae. At this stage, the fish is put in closed pots for about 12–24 hours, then removed, the dead maggots which have come to the surface are thrown away, and the fish is carefully dried in the sun. It is said that the resulting product will keep for about 9 months and is resistant to fly larvae. The author tried to investigate this phenomenon in the Eykman Institute in Batavia. He attempted to find some sort of antibiotic activity in the end product but was not successful.

The quality of the salt is of importance especially in respect to the calcium and magnesium contents and perhaps the microorganisms found in it. Much also depends on unknown factors; for example, in Holland pickled herring (pekelharing) can readily be prepared from herring caught in the North Sea, but those from the (former) Zuider Zee are not suitable since they do not acquire the characteristic flavor of the product.

V. Miscellaneous

In many parts of Indonesia, cleaned fish (*Lates* and *Stolephorus* spp.) are mixed and kneaded or pounded with an equal weight of tapioca and about 20% salt. The mixture is made into long rolls, which are steamed, sliced, and dried into thin disks. Fish as well as shrimps (*Palaemon* and *Penaeus*) can be be used for similar preparations called "krupuk." They have a very high keeping quality when dry. Sometimes sugar and eggs are added before steaming. The product is fried in oil before eating and is highly valued by the local populations and by others.

Makassar fish (red fish) is a very remarkable product manufactured near Makassar (Celebes, East Indonesia). It consists of small salty fish in a spicy red sauce and is used as a condiment. The fish (*Engraulis* and *Stolephorus* spp.) are decapitated and placed in earthenware pots with a large amount of salt. After a few days the product is mixed with "angkhak" (an intensely red-colored rice product) and ragi (prepared from rice flour infected with yeasts and fungi), and spices. After a few days the fish and the liquid become a deep red. The product is sold in glass bottles; it contains about 65.8% moisture, 15% protein, 0.4% fat, and 16.9% ash.

In the Solomon Islands, fish are cleaned and boiled for 30 minutes in 3 parts sea water and 1 part coconut water, boned, broken into small pieces and slowly dried for 24 hours over a fire. The resulting flakes keep well and are a good source of protein (analyzing 56.3% crude protein) (Peters and Wills, 1957).

Angkhak (red rice) is imported from China. It is prepared by inoculating cooked, highly milled, white rice with angkhak powder, which contains the deep red-colored fungus *Monascus purpureus* Wentii. After 6 days of storage in a cool environment, the product (consisting of red-colored rice grains and fungus mycelium) is ready; it is then dried.

Nguyen-Thi-Lau and Richard (1959) describe two fish preparations used by the poorer classes in Vietnam: "mam ca" is prepared at home from eviscerated fish salted and then coated with rice flour and sugar, and contains 26–29% protein; "ca kho" is made from dried salted fish and is eaten with rice, or among rich people, it may be used as hors d'oeuvres. Both are cheaper than fresh fish.

Attention in many countries today is given to edible fish protein concentrate, deodorized or nondeodorized, manufactured from either fresh fish or first-quality commercial fish meal. Such a fish flour, with 75–80% protein and a high calcium content, would in principle offer great possibilities if made from local fish and therefore cheap. It is easy to pack, inexpensive to transport, and keeps well. With all these advantages there are nevertheless a few problems. Nondeodorized fish flour when not manufactured in a hygienic way may become a source of bacterial infection. Deodorized fish flour, usually sterilized during a solvent extraction process, does not have this disadvantage, but solvent-extracted foods are often (and usually erroneously) regarded unfavorably because of the alleged association with carcinogenic substances.

Fish flours for human consumption are under study (or even produced on a small scale) in a number of countries in Southeast Asia, such as the Philippines, Netherlands, New Guinea, Indonesia, Thailand, and Burma. One of the most promising experiments has been with dilis flour in the Philippines (Alcaraz-Bayan and Leverton, 1957).

Richard *et al.* (1960) analyzed industrially prepared canned fish, fish sausages, and fish flour. While all these products supply concentrated and stable protein, it is not clear whether the population will accept them.

VI. Summary and Conclusions

An attempt has been made to indicate why the study of the simple but little known fish preservation methods in Southeast Asia is important from a scientific as well as a practical point of view. In many tropical countries, the native diet contains relatively little animal protein; often the main source is fish. Increasing the production of fish, both salt- and fresh-water fish, seems to offer the best possibilities for raising the animal protein level of the national diet in these countries. The economic level of most of the population is low; among the factors limiting greater consumption of fish are the high cost of imports and the lack of efficient methods for preserving the indigenous supplies. It is not generally appreciated in the technically developed countries, even in countries having a low economic level, that modern methods of fish preservation, such as refrigeration and canning, tend to make fish products far too expensive to be used freely by the general population.

Most interesting to the biochemist and food technologist are fish pastes, salted and partially dried fish products, fish sauces, and fish flour. It is probable and at least proven for the few products studied in these categories that, although enzymes of the fish itself along with bacterial enzymes are responsible for the alteration of the fish meat (partial or total hydrolysis of the proteins, disintegration and eventual liquefaction of the meat), certain of the bacteria produce the typical flavors during the maturing process. When fish proteins are hydrolyzed by mineral acids or alkali and suitably treated, they produce liquids resembling fish sauces; these liquids, however, are not comparable (as far as flavor and certain other qualities are concerned) with real fish sauces prepared in the traditional ways.

From the biochemical point of view, salted and dried fish products are less interesting than the sauces and pastes. Many problems are still unsolved. Since purified salt is usually too expensive in this part of the world it would be worthwhile to investigate the inorganic impurities which influence the taste and keeping qualities of the products. There are also problems in connection with off-color (red coloration) and off-flavor (according to local standards), which have not been extensively studied.

Only very few studies have been made and little is known of what really happens in the fish-product processes described in this paper. The chemical composition of the intermediate and end products in fish pastes and sauces is for the most part *terra incognita*. Our knowledge of the beneficial influence of added carbohydrate (rice and other cereals, sugar, bran, etc.) and other materials on the properties and quality of pastes and sauces is equally deficient. Flavor problems have hardly been investigated at all. Studies in the fields of biochemistry and microbiology could do much, however, to clarify the numerous problems and underlying biochemical reactions. They might well lead to better understanding and to more standardized methods of fish preservation in this part of the world, resulting in higher quality products of better keeping capacity in the tropical climate.

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CHAPTER 9

Whale Products as Food

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I. Introduction

Unlike most other peoples, the Japanese have long been eaters of whale meat and other whale products because of their dependence on marine sources for edible animal protein. Japan being a small insular country, livestock supplies have never been adequate. The people therefore early took to the sea; and as the fishing industry grew, so did whaling. The history of Japanese whaling can be traced back several centuries. As an industry, Japanese whaling differs from that of other countries in that the objective is the production of meat and other edible products as well as oil.

II. Catch Restrictions

Although there are more than sixty species of whales, only the large species are suitable for big-capital operations from the economic standpoint. But since indiscriminate catching of the large species that resulted from growth of the whaling industry gave rise to fears of stocks being seriously depleted, an International Whaling Commission was established to devise means for their conservation. Among the restrictive provisions adopted by this Commission was one listing the species that might be caught and the permissible minimum body length of each species (see tabulation).

Blue whales (*Balaenoptera musculus*) 70 ft.
Fin whales (*Balaenoptera physalus*) 57 ft.
Humpback whales (*Megaptera nodosa*) 35 ft.
Sei whales (*Balaenoptera borealis*) 40 ft.
Sperm whales (*Physeter catodon*) 38 ft.

With rare exceptions, therefore, whales of the various species actually caught are generally larger than the minimum limits imposed by the International Whaling Commission. One specimen measuring above 100 ft. in length is known to have been caught.

Most of the countries that engage in whaling, and all of those engaged in Antarctic whaling, are represented in the International Whaling Commission. This body has worked out numerous provisions relating to maintenance and conservation of whale stocks; these provisions are revised from year to year to meet changing conditions.

Provisions relating to matters other than whale species and body lengths that have a direct bearing on the quantity of products obtained from whales caught in the Antarctic are the following as established in 1957.

(*a*) The total number of whales other than sperm whales that may be caught during one whaling season is 14,500 blue whale units.

"Blue whale unit" is a unit devised for convenience of computation, the conversion of the various species in terms of blue whales being fixed as follows:

1 blue whale = 2 fin whales = 2.5 humpback whales = 6 sei whales

This conversion rate is without scientific backing. It is based rather on the number of whales of each species from which approximately the same quantity of oil can be obtained as from one blue whale, and hence is nothing more than a system born of long experience.

(*b*) Taking of humpback whales is restricted to 4 days during the Antarctic season.

(*c*) There is no restriction on the number of sperm whales that may be taken.

(*d*) Whale carcass must be completely processed within 30–35 hours after the catch.

The average number of whales of each species caught in accordance with the provisions of the International Whaling Commission by the fleets of the various participating nations from 1959/60 to 1961/62 are shown in Table I. Table II gives the 1959/60 to 1961/62 average total Antarctic catch compared with 1949/50 to 1951/52. This shows the drastic decline in blue and humpback whales. Although Antarctica is the major production area of the world, whales are also caught at other places, as shown by the International Whaling Statistics (Anonymous, 1962). Major catch

TABLE I[a]

ANTARCTIC (INCLUDING SOUTH GEORGIA) WHALE CATCH: AVERAGE FOR 1959/1960–1961/1962

		Species of whale					
Country	Unit[b]	Blue	Fin	Humpback	Sei	Total	Sperm whale
Japan	No	688	9,888	164	1,355	12,095	1,338
	BWU	688	4,944	66	226	5,924	—
Norway	No	128	8,594	76	632	9,430	1,609
	BWU	128	4,297	31	105	4,561	—
U.S.S.R.	No	410	4,259	431	1,465	6,565	1,032
	BWU	410	2,130	172	244	2,956	—
U.K.	No	88	2,826	83	903	3,900	349
	BWU	88	1,413	33	150	1,684	—
Netherlands	No	50	1,639	34	28	1,751	222
	BWU	50	820	14	5	889	—
Falkland Isles	No	3	675	—	467	1,145	86
(1960/61–1961/62)	BWU	3	338	—	78	419	—
Argentina	No	6	467	—	426	899	33
(1959/60 only)	BWU	6	234	—	17	311	—
S. Africa	No	9	1,381	13	118	1,521	75
(1956/57 only)	BWU	9	691	5	20	725	—
Panama	No	107	2,115	199	—	2,421	309
(1955/56 only)	BWU	107	1,058	80	—	1,245	—

[a] Yearbook of Fishery Statistics (FAO), Vol. 14, 1961.

[b] No = number of whales; BWU = blue whale units.

TABLE II

ANTARCTIC (INCLUDING SOUTH GEORGIA) WHALE CATCH: AVERAGE FOR 1949–1951 AND 1959–1961

		Species of whale					
Season	Unit	Blue	Fin	Humpback	Sei	Total	Sperm whale
1949/50–1951/52[a]	No	6,120	20,681	1,780	900	29,481	4,393
	BWU	6,120	10,341	712	150	17,323	—
1959/60–1961/62[b]	No	1,367	27,810	787	4,870	34,834	4,619
	BWU	1,367	13,905	315	812	16,399	—

[a] Yearbook of Fishery Statistics (FAO), Vol. 4, Part 1 (Production), 1952–1953.

[b] Yearbook of Fishery Statistics (FAO), Vol. 14, 1961.

reductions were introduced in the catch season 1963/1964, bringing the total outtake down to 10,000 blue-whale units. This was, according to the Director-General of FAO, not sufficient to save the stocks, so he appealed in 1964 for further restrictions and fixed quota for all species.

The humpback whale was protected at all times south of the equator and the blue whale was protected south of 40° south latitude except between 9° and 80° east longitude and north of 55° south latitude.

It will be noted that when the figures for the various species are converted to terms of blue whale units, their total for a season does not coincide with the seasonal maximum total of 14,500 heads stipulated by the International Whaling Commission. The reason for this discrepancy is easy to explain:

Throughout the Antarctic season, the total of whales caught by each fleet is reported weekly by the Government concerned to the Commission headquarters located in Oslo. And when the total of 14,500 is approached, the headquarters fixes the day on which operations are to end and notifies all the fleets. Since the notice is given approximately a week in advance, the grand total for the season is bound to be slightly more or less than 14,500 because of the impossibility of the central headquarters estimating exactly the number that will be taken during the time intervening between the dispatch of the notice and the season's end.

The meat and other products obtained from all species, except the sperm whale, caught by Japanese fleets (Table I) are brought to Japan for use as food for its people. There is little demand for the sperm whale products because they do not seem to meet Japanese taste.

III. Anatomy of the Whale; Weights of Various Parts of Carcass

Although the body length of a whale can be measured easily enough, accurate total weight is difficult to obtain because of the huge size of the carcass. So while estimates of the relation of body length to weight have been made, the actual relation has never been accurately worked out, probably because there is no acute practical need for doing so.

Although Japanese fleets have never been able to weigh a whale carcass whole, weights of all the parts of the carcass have been taken for several dozen specimens. In Tables III and IV are given the weights obtained for all the parts in fin, blue, and sperm whales.

The above total figures of course do not represent the true weight of the whales weighed; some 10% should perhaps be added to allow for the blood and other liquid substances lost during the processing. That, however, is at best only a rough estimate.

TABLE III
WEIGHTS OF PARTS IN BALEEN WHALES IN 1950–1951
(*in kg.*)

Species and sex:	Fin female	Fin male	Blue female	Blue male
Body length (ft.):	57	67	78	83
Blubber				
Blubber	3,351	5,004	11,068	11,768
Head blubber	616	1,177	2,122	2,370
Blubber of ventral groves	2,227	3,965	12,305	11,200
Blubber of lower jaw	514	840	1,460	2,205
Flukes	245	332	625	546
Total	6,953	11,318	27,580	28,089
Meat				
Meat	16,213	19,889	25,860	40,954
Ventral meat	662	237	885	3,406
Connective tissues	753	1,684	—	—
Total	17,628	21,810	26,715	44,360
Internal organs				
Heart	162	207	430	412
Lungs	343	414	730	960
Tongue	844	1,343	1,938	2,708
Stomachs	321	250	223	420
Esophagus	79	22	ND[a]	67
Small intestine	334	177	1,001	824
Large intestine	347	607	667	380
Pancreas	28	20	ND	40
Spleen	4.5	5	ND	16
Kidney	134	142	262	290
Liver	397	503	625	1,047
Bladder	16	21	ND	22
Penis (uterus and vagina)	0.5	44	ND	105
Testes (ovaries)	30	5	39	64
Diaphragm	142	218	325	490
Internal fats	770	1,769	2,798	5,952
Total	3,952.0	5,747	9,038	13,797
Bones				
Skull	1,186	2,048	2,645	5,328
Vertebrae	2,569	3,605	6,510	10,109
Ribs	174	1,281	1,040	2,409
Jaw bones	544	880	1,668	1,907
Scapula	158	263	475	393
Hyoid bone	42	45	ND	175
Nasal cartilage	ND	110	ND	230
Total	4,673	8,232	12,338	20,551
Miscellaneous				
Gums	131	129	ND	450
Jaw ligaments	191	321	370	985

TABLE III (*Continued*)

Species and sex:	Fin female	Fin male	Blue female	Blue Male
Body length (ft.):	57	67	78	83
Miscellaneous (*cont.*)				
Baleen	184	315	465	1,053
Tendons	ND	ND	ND	ND
Flippers	226	411	912	640
Scraps	2	10	1,336	7
Total	734	1,186	3,583	3,135
Grand total	33,940.0	48,293	79,254	109,932

[a] ND: Not determined.

TABLE IV
WEIGHTS OF PARTS IN SPERM WHALES IN 1950–1951
(*in kg.*)

	Body length (ft.)			
Parts	46	48	51	54
Blubber				
Blubber	6,880	5,938	6,200	5,827
Head blubber	3,306	4,223	5,015	6,482
Blubber of lower jaw	160	150	160	250
Tail flukes	318	295	479	568
Dorsal fin	—	—	—	—
Blubber of flipper	226	190	270	—
Other blubber	37	85	70	—
Total	10,927	10,881	12,194	13,127
Internal organs				
Heart	97	109	95	102
Lungs	136	150	214	363
Tongue	90	173	150	140
Gum	—	—	—	—
Esophagus	—	—	—	64
Stomachs	210	199	210	301
Small intestine	297	285	217	260
Large intestine	102	131	123	162
Pancreas	—	—	—	4
Kidney	170	138	133	172
Liver	463	492	380	517
Bladder	—	—	—	—
Testes	—	—	—	11
Penis	—	—	—	83
Internal fats	250	280	197	347
Diaphragm	157	209	196	—
Others	5	—	126	—
Total	1,977	2,166	2,041	2,526

TABLE IV (*Continued*)

	Body length (ft.)			
Parts	46	48	51	54
Bones				
Skull	1,370	1,873	2,020	2,745
Vertebrae	1,385	1,452	1,941	2,337
Ribs	382	530	630	676
Jaw bones & teeth	84	175	300	326
Scapula	96	90	110	150
Hyoid bone	—	—	—	2,223
Pharyngeal bone	—	—	—	135
Other bones	336	404	290	10
Total	3,653	4,524	5,291	8,602
Miscellaneous				
Spermaceti sac	3,661	4,820	6,497	1,255
Fibrous head tissue	91	66	178	8,007
Spermaceti	1,275	2,078	2,371	2,020
Suprarenal body	—	—	—	—
Other	565	605	850	—
Total	5,592	7,569	9,896	11,282
Grand total	29,984	32,283	37,007	44,762

Detailed antomical investigation of various parts of the whale carcass has been made, but because of a whale's tremendous size and the consequent difficulty of determining the correct natural position of the various organs once the carcass has been dissected, it has not so far been possible to prepare an anatomical chart of a complete whale.

IV. Processing of Whale Carcass

If too much time is allowed to elapse between the catching of the whale and the freezing of its meat, the meat will lose its freshness and its value as food will thereby be reduced. Robinson *et al.* (1953) found no significant growth of *Clostridium* or aerobic bacteria in whale meat before rigor. Aerobic bacteria play a subsidiary role in the spoilage of fresh whale meat. Although the International Whaling Commission, not being concerned with the utilization of the meat for human food, allows 30 hours until start of processing, the Japanese fleets have found such time to be much too long and have set their goal at 10 hours in order to prevent deterioration in quality.

There is, however, a definite limit to the processing capacity of a whaling factory ship. When so many whales are taken at one time as to exceed the factory ship's processing capacity, it not infrequently happens that the catcherboats are ordered to suspend operation until the factory ship can catch up. Even then, if all whales already brought in cannot be completely processed in 10 hours, the excess whales are processed for oil rather than meat; such parts as are not suitable for oil production are thrown overboard.

Because Japanese fleets bring back meat and other parts for use as food, they have devised a dissection method best suited for that purpose. It differs from the method used by other countries mainly interested in the production of oil.

On the average, the total quantity of meat and other edible products from a single blue whale is 17–18 tons. It can produce 7–10 tons of choice cuts of lean meat.

V. Freezing and Salting

A. Freezing

In addition to meat, such edible products as blubber and fluke are obtained from whales. The meat is classified into red meat, tail meat, and ventral meat. Most of the blubber is used for extracting oil, but a certain portion, known as ventral blubber, is used for food. Fresh whale meat or meat frozen while fresh does not have a "fishy" flavor. This characteristic is thought to be associated with oxidative rancidity of the fat.

From the factory ship these parts are taken by small transports to a refrigeration ship where they are washed with sea water and subjected to a preliminary cooling process. Then they are cut up into cubes of suitable size (each cube weighing approximately 8 lb.), quick-frozen, and placed in cold storage chambers of the refrigeration ship. Shipment to Japan is by special reefer ships. Such organs as pancreas and liver, from which pharmaceuticals are produced, are also frozen before shipment to Japan. Drip during defrosting of whale meat, as of other meat, lowers the nutritional value. Tanaka and Tanaka (1956a,b, 1957a,b, 1958) investigated this problem. Although quick freezing generally renders less drip for most meat, frozen pre-rigor whale meat seemed to be an exceptional case in which slow freezing gave less drip. For defrosting, dielectric heating was as effective as circulating air at 10°C. (50°F.).

Sharp and Smith (1952) found that only polyvinylidene chloride film gave marked protection against dehydration and oxidation in whale meat stored at —10°C. It was found that frozen whale meat kept covered with ice glaze or adequate wrapping would keep 10 months at this temperature without deterioration (Sharp and Marsh, 1953).

B. Salting

If it were possible, the ideal would be to freeze all of the edible products. But because of the limitations of freezing and transport facilities, a part has to be salted. The salted meat also is shipped to Japan in reefer ships.

TABLE V[a]

PRODUCTION OF PROCESSED WHALE PRODUCTS BY JAPANESE FLEETS IN THE ANTARCTIC (INCLUDING SOUTH GEORGIA) IN VARIOUS SEASONS

	Products								
	Whale oil			Sperm oil			Whale meat		
Seasons	World	Japan	% Japan	World	Japan	% Japan	World	Japan	% Japan
1949/50–1953/54	352.2	31.8	9.0	32.0	4.3	12.7	34.0	25.6	74.7
1954/55–1958/59	334.8	73.0	21.8	48.3	13.5	28.5	108.6	91.8	81.1
1959/60	331.9	93.7	28.2	33.4	11.2	33.5	145.9	119.5	81.9
1960/61	343.1	101.2	29.5	36.4	12.2	33.5	166.1	136.3	82.1
1961/62	na[b]	na	—	na	na	—	na	na	—

	Whale liver oil			Other		
	World	Japan	% Japan	World	Japan	% Japan
1949/50–1953/54	0.2	0.1	50.0	1.1	0.7	70.5
1954/55–1958/59	0.2	0.2	93.3	14.9	13.0	87.3
1959/60	0.2	0.2	100.0	14.9	13.0	87.3
1960/61	0.2	0.2	100.0	40.5	35.7	88.1
1961/62	na	na	—	na	na	—

[a] (1) Yearbook of Fishery Statistics (FAO), 1952–1953, 1958, 1959, and 1961.
(2) Abstr. of Statistics on Agriculture, Forestry and Fisheries, Japan, 1961, 78.

[b] Not available.

The quantities of products obtained by Japan's Antarctic whaling fleets during past seasons are shown in Table V.

VI. Whale Meat and Other Products; Use as Food

A. DIRECT CONSUMPTION

Frozen whale meat, cooked very much the same as beef or pork, is widely used by the people of Japan. Also fluke and ventral blubber, both frozen and salted, are quite popular; they are either cut into small slices and suitably seasoned or cooked together with various other ingredients. Even such parts as liver, tongue, kidney, intestine, and nasal cartilage have long been eaten by the Japanese, each preparing them for the table to suit his taste; but the demand for them today is too small to make them an economic factor in the Antarctic operations. While never extremely popular, whale meat has been eaten in Europe for centuries. It was brought to London from Rouen as early as 1000 A.D. It was sold elsewhere at early dates, e.g., Utrecht in 1024, Nieuport in 1163, Damme in 1252, and Calais in 1300 (Slijper, 1962). Even today whale meat is regularly processed in Iceland and Norway. Some is exported to Britain and Germany where it is used to a limited extent for human food, but more frequently for pet food.

It must not be forgotten that whales are a very important item in the Eskimo diet. Whale meat contains 4.8% fat as compared with an average of 12% for beef.

B. Canned Food

Both frozen and salted whale meat, seasoned with sugar and soy sauce, are canned for the market in large quantities. Also put up in cans are roast whale meat, whale meat "sukiyaki," and corned whale meat, the last being somewhat similar in taste to corned beef. Outside of Japan some frozen whale meat is canned and sold as meat roll stews and as meat and vegetable packs of "steak and kidney" (Anonymous, 1949a).

C. Sausage

To the two main ingredients, frozen or salted whale meat and tuna, are added various condiments and seasoning; the mixture is packed in artificial casing and then boiled and pasteurized. Schulze (1949) found sausages containing 3.6–4% whale meat meal to be perfectly good. However, 10% gave a too fishy taste.

D. Edible Gelatin

This is produced from the head blubber and connective tissue around spermaceti, both frozen and salted. Japan is probably the only country in which the production of gelatin from whales has been developed as an industry, and even in Japan there is only one factory devoted to this. The factory also produces gelatin for photographic and other industrial uses; its production constitutes a very substantial portion of total gelatin production in Japan.

Characteristic properties of edible gelatin produced from whales are given in Table VI.

E. Rengi

In Iceland a dish is made from whale belly by pickling the fat in acid. Rengi has a cucumber-like taste. Most foreigners do not like it (Slijper, 1962).

F. Drying

Robinson *et al.* (1949) found that the total number of bacteria in dried whale meat was low for this type of product. They found about

TABLE VI
PHYSICAL AND CHEMICAL PROPERTIES OF WHALE AND COW GELATIN

Kind of gelatin	Moisture (%)	M.P. (°C.)	S.P. (°C.)	Viscosity[a] (sec.)	Jelly strength[b]
Whale (blubber)					
Gelatin A	—	28.9	25.0	56.3	582
Gelatin E	15.89	30.4	26.3	107.6	580
Gelatin F	17.70	31.5	26.6	161.7	1275
Cow					
DEG (Germany)	18.11	33	27	55.3	339
Winterthur (Swiss)	18.63	34	27	73.5	314
Nelson (England)	17.43	31.5	26	60.4	340
A Company 1	19.58	34	28	55	320
A Company 2	19.57	33.5	28	57	313
A Company 3	19.18	32.5	28	59.3	301
B Company 1	18.26	34	28.4	112.9	515
B Company 2	17.77	31.8	26.7	67	280

[a] Viscosity is shown in seconds of 50 ml. gelatin solution at 50°C. by the Redwood viscosimeter.

[b] Jelly strength is shown of 5% or 10% solutions.

equal numbers of *Clostridium* and aerobic bacteria. No *Clostridium* pathogenic to the mouse was found.

G. PICKLING

In Norway, the same type of brine and vinegar procedure used for their "silver herring" product has been successfully used for whale meat (Anonymous, 1949b).

VII. Whale Oil

The collective term "whale oil" as popularly used includes oil obtained from blue whales, fin whales, humpback whales, and sei whales, but not that from sperm whales. The oils of these four species are so similar in character that no distinction is made between them by the trade.

Whale oil, after being hardened by hydrogenation and deodorized, becomes the raw material for the production of margarine. The equipment and process used for this hardening and deodorization are the same as in the case of ordinary fish oil.

Since whale oil is extracted by causing the protein to be digested under steam pressure, it contains far less impurities than does ordinary fish oil produced as a by-product of fish meal by subjecting the fish to hydraulic pressure. As raw material for hardened oil, therefore, whale oil is considered superior to fish oil.

Sperm oil, unlike ordinary whale oil which is made up of glycerine and fatty acids, is a compound of higher fatty alcohols and fatty acids, hence it is said to be injurious to health if eaten, because of the presence of higher fatty alcohols. It has actually been proven by animal feeding tests that overuse of feed containing sperm oil can prove fatal.

In coastal regions of Japan where sperm whales are caught, however, the people have long been using sperm oil regularly in their cooking without any indication of special harmful effects traceable to the use of the sperm oil. In human feeding tests in which individuals were given sperm oil daily equal in quantity to the average daily intake of fats in Japan, it was noted that the rate of absorption from the digestive organs was about the same for sperm oil and other fats and hence that there was little nutritive difference between them. In other human feeding tests employing margarine made from hydrogenated oil, the main ingredient of which is sperm oil, nothing could be found of harm from the standpoint of nutrition. Although intensive study of this problem is being continued in Japan, past tests appear to have revealed enough to give room for doubt as to the soundness of the view so long held that sperm oil is harmful to the human body.

VIII. Research on Whale Meat

The only use made of whale meat in England at present seems to be for livestock feed. But immediately after World War II when that country was suffering from acute shortage of beef, production of whale meat was begun in order to supplement the country's meat supply; both fresh and canned meat was supplied to the people.

Since this was a field in which the British people had little experience, a basic study of whale meat was then begun by personnel of the Food Investigation Board and the Low Temperature Research Station with cooperation from members of the whaling industry. The results of their studies are reported in Special Reports No. 58 and 59 (1953) of "The Food Investigation" published by the Food Investigation Board.

But in Japan, where whale meat has been used as human food for so long, biological research on whales for scientific purposes and more practical study of whale meat for use as food have been pursued quite extensively. Regarding the latter study, however, there is relatively little to be found in the way of published reports, the reason being that most of such study is carried on by the whaling companies for the purpose of improving their respective production, preservation, and processing.

IX. Conclusion

Together with the conservation of the whale stock, the complete utilization of the whale carcass is an important mission of the International Whaling Commission. It is for this reason that one of the provisions of the Commission stipulates that such parts of the carcass as are not used for food must be put into the press-cooker for separating oil, in order to obtain the maximum quantity of oil from each whale.

Compliance with that stipulation may appear to be in conformity with the purpose of "complete utilization." In practice, however, when lean meat is thrown into the boiler the protein is dispersed; the dispersed protein not only increases emulsion in the oil, but tends to reduce the oil yield by adsorbing some of the oil on its surface. Therefore, use of the meat for human food would appear to be more significant and in closer conformity to the Commission's important mission than is the requirement of "complete utilization" as laid down by the International Commission. If all of the fleets of other countries that operated in the Antarctic in the 1958 season had produced whale meat in the same proportion as the Japanese fleet, total production would have been 270,000 tons.

Since the huge quantity of whale meat is a source of edible protein obtainable in a short period and with relative ease as a by-product, the possibility of supplying it to countries where people are suffering from shortages of animal protein deserves serious study as one of the major problems bearing on future Antarctic whaling.

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CHAPTER 10

Fish Sausage Manufacturing

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I. Introduction

Fish sausage manufacturing in Japan is attracting world wide attention because of the rapid expansion of the industry, a growth rate that was never expected even by the entrepreneurs. Before the Second World War, experimental preparation of fish sausage had on occasion been tried by a few fish processing technologists, with rather unsuccessful results. The lack of suitable packaging materials was perhaps the main technological deterrent to the introduction of the new fish product in Japan, but in addition, consumers were not ready to accept a product of this kind. The fish sausage industry in Japan was actually begun in 1953 by small-scale manufacturers. Average daily production at that time was low, but the industry gradually grew and was taken over by large fishing firms that were able to obtain abundant raw material by using their own fishing fleets.

The remarkable increase in production may be seen in Table I: the 1962 output is almost twenty-five times larger than that of 1954. The following factors account for this rapid growth.

TABLE I
ANNUAL PRODUCTION OF FISH SAUSAGE, 1954-1963

Year	Amount (metric tons)	Year	Amount (metric tons)
1954	4,081	1959	64,697
1955	11,978	1960	85,442
1956	26,103	1961	91,639
1957	38,217	1962	114,125
1958	49,190	1963	118,369

(1) The technological groundwork for the new industry had already been laid by the "kamaboko" manufacturers. "Kamaboko," another Japanese fish product, resembles meat loaf. The manufacture of fish sausage is quite similar to that of "kamaboko," except for the use of pork fat, spices, film casings, etc. Annual production of "kamaboko" is close to 0.5 million metric tons.

(2) A general improvement came about in the manufacture of synthetic materials, such as rubber hydrochloride or vinylidene chloride, for film casings. Prewar types of rubber hydrochloride were not suitable for food packaging because they left an unpleasant odor in foodstuffs. Postwar elimination of this drawback, along with the introduction of a new synthetic film, vinylidene chloride, aided development of the industry.

(3) A change has taken place in dietary patterns in Japan since the war, marked by increased consumption of meat, meat products, and milk, although the rice-eating habit is still firmly established. Thus, fish processed in the style of meat sausages has appealed to customers.

(4) The relatively low prices of fish sausages have fostered the industry; a 100-g. piece costs only 30 Yen (8.4 cents in United States currency). This brings wide marketability in rural sections where the living standard is lower than in urban areas.

(5) The use of chemical preservatives has been legally permitted in Japan and now plays a significant role in maintaining acceptable shelf-life of the sausages. (Time and temperature employed in processing are not sufficient to destroy all microorganisms.)

II. Chemical Aspects

From the standpoint of consumer preference, the resilient quality of the finished fish sausage is an important factor influencing its general acceptance. The manufacturer's primary concern, therefore, is learning how to retain resiliency in the final product. This resiliency is related not only to the flavor but also to the keeping quality of the sausages. If the texture of fish sausage is coarse and inelastic, water exudes from the meat during storage and forms a small pool, ideal for bacterial growth, between film and skin.

The effect of resiliency is more pronounced in kamaboko since the latter are generally marketed without the film casing that averts direct microbial invasion. Exposure of the product surface of kamaboko permits rapid spoilage by allowing oxygen, that may promote bacterial growth inside, to enter freely. But the degree of air penetration differs with the texture. The resilient product is able to resist spoilage longer than that lacking this property (Yokoseki, 1959).

An explanation proposed for the elastic structure of agar-agar or gelatin jelly, an intertwined arrangement of their long-chained molecules that permits retention of water, can be applied to the resiliency of fish sausage or "kamaboko" (Okada, 1959a). The myosin of the fish flesh supposedly affects its structure. Apart from this, Okada and Migita (1956) observed by microscopic examination a fine network in thin slices of extra quality "kamaboko." Their finding led the authors to an opinion that a network structure of not only colloidal, but also microscopic, dimension may have something to do with the elastic property of "kamaboko," though an assumption that the elasticity of gel is due to the presence of a network structure of colloidal dimension has been generally accepted.

Miyake and Hayashi (1957) made a determination of the myosin content of 21 different fish (Table II). They observed that fish with less myosin gave a weaker resiliency when processed into "kamaboko."

Dark-fleshed fish, such as tuna or mackerel, show a comparatively small amount of myosin. Shimizu and Shimidu (1958) noticed, however, that myosin decreases in amount with storage time after catching, and suggested that the myosin yield might be larger in the flesh immediately after the capture.

Myosin in muscle tissue seems to be in an orderly, fixed arrangement, not free to regroup for the making up of a network. Possibly myosin must be treated with certain neutral salts before it becomes capable of such basic reorientation.

The reason for mixing common salt into fish sausage preparations is unquestionably to modify the flavor, but at the same time it affects the extraction of myosin fraction from the fish muscle tissues. The key factor in reinforcing the jelly strength of fish sausage is in effect the myosin solubility. The use of salt, alkali, and/or polyphosphates is considered effective for this purpose.

Table II

Amount of Myosin in Various Species

Species[a]	Dry matter (%)	Myosin (%)
1. Croaker (*Nibea argentata*)	19.22	9.97
2. Croaker (*Pseudosciaena manchurica*)	18.96	9.97
3. "Hira" (*Ilisha elongata*)	20.40	8.22
4. Silver conger eel (*Muraenesox cinereus*)	22.08	8.38
5. Cutlass fish (*Trichiurus japonicus*)	29.95	2.62
6. Ray (*Dasyatus akajei*)	18.57	2.27
7. Pacific saury (*Cololabis saira*)	30.14	6.97
8. Flying fish (*Cypselurus agoo*)*	28.92	9.90
9. Turbot (*Limanda angustirostris*)*	20.42	6.99
10. Bluefin tuna (*Thunnus thynnus*)	23.27	8.90
11. Mackerel (*Scomber japonicus*)*	22.29	6.23
12. Sardine (*Sardinops melanosticta*)	23.92	6.60
13. Cuttlefish (*Sepia esculenta*)	26.53	9.64
14. Shark (*Galeorhinus manazo*)	24.34	9.99
15. "Mutsu" (*Scombrops boops*)	23.90	14.62
16. Sea bass (*Lateolabrax japonicus*)	20.42	12.80
17. Horse mackerel (*Trachurus trachurus*)	24.03	11.15
18. Ocean perch (*Sebastiscus marmoratus*)	20.17	9.75
19. Squid (*Sepiotanthis lesoniana*)	22.59	13.05
20. Snapper (*Branchiostegus japonicus*)	19.50	12.31
21. "Hata" (*Epinephelus septemfasciatus*)	18.44	11.42

[a] Fishes 1–7 were sent frozen to the laboratory. Japanese common names are in quotation marks; very fresh samples are marked with an asterisk. From Miyake and Hayashi, 1957.

A. Sodium Chloride and Myosin Extraction

Using mackerel meat, Shimizu *et al.* (1954b) observed that the amount of extractable myosin varies with the concentration of sodium chloride. A strength between 1.2 and 1.5 M NaCl solution gave a maximum extraction of myosin as well as the best resiliency in the finished product. Use of common salt in such an amount is not practical, however, since it makes the product very salty.

B. pH of Raw Jelly

While grinding and mixing the raw fish jelly, adjustment of pH value to a pertinent range is another means of extracting myosin. The extractability of myosin is greater when the pH of the flesh is slightly alkaline.

Shimizu *et al.* (1954a) demonstrated that the jelly strength of the finished product was lower, although the amount of extracted myosin was greater, on the alkaline side. Perhaps high pH media prevent network formation. Okamura *et al.* (1959) reported a close correlation between the pH value of raw jelly and jelly strength of the cooked product and added the observation that the jelly strength decreased as the pH value of the raw fish jelly exceeded 7.5. In cases where tuna or marlin is used as the main ingredient in fish sausage, a slight shift of pH to about 7 may be effective in attaining good resiliency, because the original pH values of the flesh of these fish lie in the range 5.6–6.0, i.e., more acid than that of white fish. No adjustment of pH is required to make fish jelly from species such as Alaska pollock, croaker, and lizard fish, since the natural pH values of the flesh from these species range between 6.5 and 7.0 or more.

C. Polyphosphates

Polyphosphates are added to raw fish jelly in order to attain greater resiliency in the finished product. By measuring the jelly strength, breaking strain, and amount of expressible water, Okada and Yamazaki (1958) examined the effect of polyphosphates on the texture of fish sausages. Concentrations from 0.2 to 0.5% of the product were found most effective, with the upper limit impairing taste. With regard to both palatability and meat-binding, concentrations between 0.2 and 0.3% are preferable when using commonly available polyphosphates.

The effect varies with cooking temperature. Resiliency increases proportionally with the temperature up to 80°C., but drops sharply when the temperature exceeds 90°C. This is explained in part by excessive denaturation of meat protein at the higher temperature, and in part by hydrolysis of polyphosphates to less effective orthophosphates under heating. Tripolyphosphates have been found best for improving resiliency.

Shimizu and Shimidu (1953) examined the effect of NaCl, LiCl, and KCl for their effect on the solubility of myosin from mackerel meat and found no appreciable differences in the effects of these salts. Anions, however, seem to affect the solubility to some degree. Using potassium salts with different anions, the strengthening effect on the jelly increased in the following order: $SO_4^- < Cl^- < Br^- < I^-$. Iodine ions proved most active in solubilizing the proteins.

D. Setting Phenomenon of Raw Fish Jelly

Raw fish jelly normally has a glutinous texture immediately after the preparation. This is a commonly observed characteristic of fish meat that has been ground and mixed with sodium chloride. On standing, this texture changes, gradually giving a kind of elastic response. The phenomenon of losing the adhesive property of the ground meat has been referred to by "kamaboko" manufacturers as "setting" (literally translated from Japanese term). It is believed to be disadvantageous because "set" meat is hard to mold into a product of desirable shape. The same is true of fish sausage processing, since raw fish jelly with low viscosity is difficult to stuff into film casing.

The explanation for the setting phenomenon has not been found. After extensive works by using various kinds of metallic and alkali earth salts, Migita and Okada (1952) postulated that the water-binding capacity of fish muscle protein is playing an important role in these physicochemical changes. These workers assumed that the setting is caused by hydration of protein molecules on which certain anions are adsorbed by their surface active property. These molecules are subsequently brought into a kind of network formation. The solubility of myosin is reduced as the setting proceeds in the raw fish jelly. Myosin molecules arrayed in the network may be no more soluble than those just dissolved in neutral salt (Okada, 1959b).

Easiness of setting varies with each species of fish. There seem to be few effects that can be attributed to environmental conditions. Fish species grouped according to the degree of ease with which their flesh sets are given in Table III. Much more research is needed to explain the specific characteristics of setting.

TABLE III
A GROUPING OF FISH ACCORDING TO EASE OF SETTING[a]

Fish that set readily	Sardine, round herring, lizard fish, flying fish, barracuda, mackerel, hairtail, horse mackerel, goby, Alaska pollock, turbot
Fish that set moderately well	Croaker, flounder, plaice, cod, bonito, yellowtail, big-eye tuna, sea bass, rockfish
Fish that hardly set	Conger eel, carp, saury, dolphin (*Coryphaena sp.*) yellowfin tuna, black marlin, shark

[a] From Okada, 1959b.

III. Raw Materials

A. RAW FISH

Almost any kind of fish can be used to make fish sausage, since chopping and grinding of the flesh are involved in the course of processing. In Japan, however, tuna varieties are preferred, possibly because the meat color stands up well in the finished product. Croaker or lizard fish are used in kamaboko, where a white product is preferred.

Yellowfin tuna, big-eye tuna, and black marlin are the main species employed but whale meat may also be used. Bluefin is most often consumed "sashimi" style (one of the indispensable dishes for a Japanese cook), and is seldom processed into fish sausages. Albacore is not used either, as this variety is generally canned or frozen for subsequent canning.

In the quick expansion of the industry, the tuna shortage has become a significant problem and recently such fish as croaker, Alaska pollock, horse mackerel, and shark have been mixed with tuna. These fish are probably chosen for two reasons: (1) their suitability for this product and (2) their abundance.

More than two species of fish are usually blended, because tuna flesh alone does not give the product sufficient resilience.

B. STARCH

In general, starch is added, in the proportion of 5–10% of the sausage weight, as a thickening. This is not necessary, however, when fish yielding a good jelly strength are available. Alpha-type starch, moreover, does not improve the resilient texture. Too much starch might be construed as an attempt to replace fish with a cheaper ingredient.

Potato starch gives better jelly strength than wheat starch, but is usually loaded with more bacteria, particularly heat-resistant spore formers of soil origin. These spores may survive heat processing and cause spoilage during transportation and storage of the product. An effort to reduce the bacterial contamination of potato starch has been made by producers with promising results. Corn starch is satisfactory.

C. FAT

Since the major varieties of fish made into fish sausage are normally lean, fatty tissue of pork and/or shortening oil are generally mixed into the product. Diced pork fat, with about 0.5 cm. of edge, is mixed into the raw fish jelly, so that the cut surface of sausage may show a mosaic pattern of white fat tissue scattered throughout the red flesh portion. An average amount of fat added is about 5%, although this differs considerably with individual maker's recipes.

D. SPICES

Spices are generally added for flavoring; these include pepper, nutmeg, mace, allspice, sage, clove, cinnamon, cardamon, garlic, onion powder, and mustard. Milled spices, however, can also be a source of contamination by soil-borne bacteria. To render a smoke aroma, a liquid smoke concentrate needs to be employed, as smoke per se would normally not permeate artificial casings.

E. Food Additives

Because of the dull color of cooked tuna or whale meat, coloring agents such as amaranth, erythrosin, and Ponceau SX are widely employed by the industry.

Sodium or potassium nitrite can be used to retain the color of tuna and whale meat. The maximum permissible amount of the nitrite is 0.05 g./kg. of the product. The nitrite is added when the raw tuna or whale meat is cured with common salt under refrigeration for 10–20 hours.

Polyphosphates are incorporated into the fish sausage during the grinding process. Basic polyphosphates make the flesh alkaline and affect the solubility of protein as mentioned earlier (Section II,C). Pyrophosphate or tripolyphosphate exerts a weak bacteriostatic action, possibly due to its capability of chelating minerals (Vishniac, 1950; Dirheimer and Jean-Pierre, 1956). The growth of *Bacillus pantothenticus*, which causes "softening spoilage" of fish sausage, can be partially arrested by these polyphosphates (Uchiyama and Amano, 1959).

Taking advantage of the broad-minded attitude of public health authorities, three different chemical preservatives are being used by the industry. In Japan, legally approved preservatives, confined to fish sausage and "kamaboko," are 5-nitro-2-furfural semicarbazone, nitrofuryl acrylamide, and sorbic acid. Additions of 0.005 g. of the nitrofurazone/kg., or 0.02 g. of the acrylamide, or 2 g. of sorbic acid are designated as maximum permissible amounts.

It is quite obvious that the industry could have developed to the recent level of production more quickly if the shelf-life of the fish sausage had been improved from the start by more extensive use of these preservatives. But there prevails some uncertainty about their toxicity. Keeping fish sausage in a refrigerated show case is more desirable, particularly at retail stores, than the use of chemical preservatives; however, the reversion of starch to beta-forms is a drawback in the storage of the product at low temperatures.

F. Casings

Artificial casings now in use are vinylidene chloride and rubber hydrochloride. No natural casings of animal origin are employed. Each film possesses its own merits and drawbacks. Rubber hydrochloride is elastic and tough, so it is shrinkable when heat processed. But it is opaque, rather permeable to gas, and liable to become brittle under direct sunlight or after long storage. Vinylidene chloride film is less permeable, transparent, and chemically inert, but is not resistant to strong mechanical injury. Both films tolerate a temperature of 100°C. for 1 or 2 hours, but lately the vinylidene chloride film is becoming more widely used.

IV. Preparation and Processing

After washing and dressing the raw fish, fillets of the proper size are placed in meat mincers of the motor-driven type in order to comminute the flesh. When frozen fish is allotted for preparation, the thawing process must come first. However, a complete thawing may not be necessary, because ordinary meat mincers operated with motors can be used on semithawed fillets. This is even an advantage, since ice crystals remaining in the tissues lessen damage from heat generated during the grinding operation.

The minced flesh is placed in a food cutter or a kneading machine and subjected to high-speed cutting or continuous grinding for about 10 min. The flesh is watched carefully for the onset of jelly formation. Whether the use of a food cutter or of a kneading machine is more beneficial for the final texture of the sausage is a matter of personal choice. Normally, a preparation from a food cutter has a less compact texture than that from a kneading machine. The latter is better for macerating the muscle fiber since a tripod pestle runs through the basin bottom; it gives a texture resembling "kamaboko," with a smooth cut surface. Owing to the friction between pestles and the bottom, the kneading machine is apt to generate heat during operation and may consequently cause heat denaturation of the fish meat protein, which is detrimental to attaining good jelly strength. To avoid high heat generation, the basin of the kneading machine is usually made of stone (granite), the pestles of wood. In some cases, crushed ice is added to keep the meat cool.

Approximately 1–2 min. after starting the operation in these machines, about 3% sodium chloride is added to the ground meat. This addition brings about jelly formation in the meat being ground, as a result of the muscle protein dissolving in the presence of salt. During the grinding other ingredients, such as starch, spices, monosodium glutamate, artificial color, and chemical preservatives, are also added. They may be mixed in, one after the other, but are usually all dissolved in water previously.

Toward the end of the grinding and mixing, diced pork fat tissue is added. This gives the mosaic pattern of fat and meat, mentioned earlier, when the sausage is sliced. Similarly, diced tuna meat that has been processed overnight with a curing agent is mixed into the ground flesh during the last part of the grinding operation. Products prepared in this fashion are called "ham-style."

It is very necessary to keep the fish jelly at a low temperature during grinding and prior to heat processing. Major Japanese fish sausage plants are now equipped with air-conditioned facilities, particularly for the butchering and grinding operations. Average temperatures of the fish jelly before heat processing range from 10° to 15°C.

The fish jelly thus prepared is then transferred to a stuffer. Stuffing is not very different from that practiced in meat sausage making. However, closing the end of the casing after the fish jelly is stuffed is much more mechanical. A semiautomatic closing machine seals one end of the casing with aluminum wire. The other end has been sealed in a similar way by the casing manufacturer before delivery. More recently, fully automatic closing machines have been developed that include a mechanism to wrap the fish jelly with a film sheet which subsequently is sealed in a high frequency field.

The sealed sausages are then taken by conveyer through the lower section of a large cooker filled with water at a temperature between 90° and 95°C., where they are heat-processed. A continuous heat processing machine is able to process about 100,000 pieces of fish sausage, each weighing 120 g., in 8 hr. Sausage with a diameter of 3 cm. are heated to a temperature of 85°C. for 20 min., then the pieces are dipped in water heated to 90°C. for 50 min.

The continuous cooker is linked to a cooling tank, in which is a conveyor similar to that in the cooker; 30–40 min. are required to cool the processed fish sausage. With rubber hydrochloride casing, the surface of the film becomes wrinkled when cooled, but a 10- to 30-sec. dip in hot water smooths it. This step, however, is not necessary when vinylidene chloride film is used.

After heat processing and cooling, the finished products are wrapped with cellophane paper, packed in cartons, and marketed.

V. Recipes

Recipes differ considerably with each plant and change with the season even in the same plant because of the pattern of fish landing. The following recipes have been obtained from five different plants. It is noteworthy that in each case either black marlin or croaker, both of which act as binding materials in fish sausage, is used.

A. WHALE MEAT AND TUNA

Equal amounts of black marlin, yellowfin tuna, and big-eye tuna	60 parts
Whale meat (blue or fin whale)	40 parts
Common salt	2–3 parts
Spice mixture	0.5 part

B. SALMON AND TUNA

Black marlin	30 parts	Wheat starch	5–8 parts
Yellowfin tuna	20 parts	Cane sugar	1.5 parts
Big-eye tuna	20 parts	Common salt	3 parts
Salmon	20 parts	Spice mixture	Not specified
Pork fat	10 parts		

C. SHARK, TUNA, AND SALMON

Black marlin	40 parts	Pork fat	10 parts
Yellowfin tuna	40 parts	Potato starch	10 parts
Shark	5 parts	Common salt	3 parts
Salmon	15 parts	Spice mixture	0.5 part

D. CROAKER AND TUNA

Due to the shortage of marlin this sausage type has been developed:

Yellowfin tuna	50 parts	Wheat starch	6 parts
Big-eye tuna	20 parts	Na-glutamate	6.2 parts
Croaker	20 parts	Cane sugar	2 parts
Pork fat	8 parts	Common salt	3 parts
Shortening oil	2 parts	Spice mixture	0.5 part

E. BLACK MARLIN

Black marlin	100 parts
Potato starch	7 parts
Na-glutamate	0.6 part
Spice mixture	Not specified

From the statement about the preceding (croaker and tuna) sausage, it should be apparent that this type (using black marlin exclusively) is rare. The firm that produces it is quite small and processes fewer than 3,000 pieces of sausage daily.

F. GENERAL REMARKS

Monosodium glutamate is frequently used to enhance fish sausage flavor. Some firms are considering the use of sodium 5′-inosinate and sodium 5′-ribonucleotide, which have appeared on the market recently. Mixing proportion of spices is another item for which exact figures have not been given. One example was a mixture of onion powder (0.1), mace (0.05), nutmeg (0.05), and white pepper (0.3) to 100 parts of fish jelly.

The fish sausage now being manufactured in Japan, could be referred to as a sort of semipreserved food, since the heat processing is not enough to kill all the microorganisms contained in the product. In other words, the product is pasteurized, not sterilized.

VI. Shelf-Life and Bacteriological Problems

A raw fish jelly, prior to cooking, may contain from 100,000 to 1,000,000 microorganisms per gram, that originate in the raw fish, starch, spices, and other ingredients. The bacterial load from the raw fish, however, seems to be less significant in relation to storage life than that from the other sources, because the bacteria involved are not heat-resistant and are killed by heat processing without much difficulty, except when the fish has been contaminated by heat-resistant types after landing and transport.

The majority of spoilage bacteria survive cooking. Changes in the bacterial flora taking place before and after heat processing are outlined in Table IV (Yokoseki, 1957).

TABLE IV
CHANGES IN MICROFLORA IN FISH SAUSAGE DURING HEAT PROCESSING

Temperature at core of product[a]	Bacterial count in 1 g. of sample	Species of bacteria identified
60°C.	5.3×10^5	*Micrococcus varians* *Micrococcus epidermis* *Bacillus megaterium* *Bacillus firmus*
65°C.	7.3×10^4	*Bacillus megaterium* *Bacillus firmus* *Bacillus subtilis*
70°C.	6.3×10^4	*Bacillus coagulans*
75°C.	3.8×10^4	Not identified
88°C.	8.1×10^3	*Bacillus subtilis* *Bacillus megaterium*

[a] Test samples were taken when the core of the product reached these temperatures; the 88°C.-sample was the finished product. The samples examined contained the ordinary mixture of fish, starch, spices, and other ingredients, except sugar.

Even when carefully handled, bacteria will be found in both the raw material and the final product. Sanitation is therefore a primary concern of both producers and distributors.

Fish sausage prepared in the conventional way may remain palatable for 2 weeks if kept under refrigeration. If exposed to room temperature, it becomes spoiled within 3 days if no preservatives are used. Sausages to which starch has been added show rapid decomposition. The elimination of starch from the ingredients may not necessarily be a prerequisite to assure good keeping properties. Contamination by aerobic spore formers, e.g., from the bacillus groups, takes place in the spices as well as during handling and transportation of the raw fish. Recently, frozen tuna fish sent to remote plants that had been newly erected in inland areas had a heavier load of bacteria than tuna that was otherwise handled.

The use of legally permitted chemical preservatives has afforded producers of fish sausage a means of extending their market into distant, rural parts of the country, since such additives may prevent spoilage for more than 3 weeks at normal atmospheric temperatures. Nitrofurazone in particular retards the growth of surviving bacilli.

Even when preservatives are used, however, there might occur a particular spoilage due to the growth of *Bacillus pantothenticus*, resulting in so-called softening spoilage, which is characterized by a flabby texture in the sausage meat. This organism is very active in splitting down starch under the low oxygen tension maintained in ordinary products, and in due course leaves a sour odor without any penetrating foul odor. Yokoseki *et al.* (1958) observed more than 10 million cells of *Bacillus pantothenticus* in 1 g. of the softened portion of fish sausage, whereas the bacterial count in the sound product was less than 10,000.

More recently, a peculiar type of spoilage, characterized by the formation of small discolored spots on the surface of the product, has been noted in fish sausage. The spots vary in color; some are brown, others black. Some form gas. Bacteriological examination revealed that the spots were dense colonies of heat-resistant organisms such as *Bacillus coagulans*, *Bacillus firmus*, *Bacillus circulans*, and *Bacillus subtilis* (Yokoseki, 1962). The portions apart from these spots contained very few bacteria. This indicates that the growth of the bacteria is limited to the area near the spots, diameters of which range from 1 to 7 mm.

The organism primarily responsible for the discolored spots was *Bacillus coagulans*, which has been reported as the causative bacteria of flat sour spoilage of canned products. It is quite thermophilic and grows well at temperatures between 40° and 50°C. The feature that *Bacillus coagulans* lacks the ability to develop on casein or gelatin may account for the fact that the spots impart very little evidence of decomposition.

Bacillus firmus or *Bacillus circulans* are frequently isolated, in conjunction with *Bacillus coagulans*, from the spots that are inflated by gas. No gas analysis was conducted on the content of these areas, but the addition of nitrite or nitrate for improving meat color might have favored the growth of *firmus* or *circulans* type, since these are able to denitrify nitrous or nitric compounds. It was also evident that the spots containing gas were seen only in the product with added nitrite.

From these findings, the preservative effect of nitrofurazone or nitrofurylacrylamide at a concentration within the legally permissible limit has become questionable. Amano and Uchiyama (1963) examined the effect of the legally permitted concentration of both nitrofuran compounds on the germination of spores of *Bacillus pantothenticus* and found no inhibition of spore germination. These bacilli showed an active growth of the cells from the stage of outgrowth after careful removal of the nitrofuran compound by washing. Thus there is presumably very little, if any, chemical attachment between the cell wall ingredients and nitrofuran compounds.

Since the optimum growth temperature of the bacteria that cause both softening and spot spoilage is 40°C., damage can be avoided by keeping the storage temperature low. The use of chemical preservatives should be discouraged, not only from the standpoint of public health but also because of the risk that the industry might lower its sanitary standards. One reason for the wide use of preservatives in Japan is that the majority of retailers lack refrigerators on their premises. Completion of the cold chain (from catch to retailing) emerges as a more attractive alternative.

VII. Quality Control

Quality control of commercial products forms part of a program of the Japan Fish Sausage Association, the central body of producers. Actual examination is consigned to the laboratory of the Japan Export Frozen Food Inspection Association under contract. Samples of fish sausage are drawn from retailers' shops and from plants at random, and are subjected to organoleptic, chemical, and bacteriological examinations.

Moisture content, pH value, starch content, and bacterial count are the main areas of examination. Determination of fat and volatile acid are occasionally made, if necessary. In 1962, the Ministry of Agriculture and Forestry introduced a standard of quality for the manufacture of fish sausage and related products. This standard is wide in scope, controlling the construction of plants, equipment, machines, handling of raw materials, ingredients, processing, chemical composition of finished product, and labeling.

As for the index of quality assessment of fish sausage, it is difficult to fix a suitable method of evaluation. However, determination of volatile acid seems workable because volatile acid, rather than volatile basic nitrogen, develops primarily on decomposition of the product (Uchiyama and Tanaka, 1958). A shortage of oxygen inside the product, assisted by impermeable synthetic casings, may favor the formation of volatile acids by bacterial action. A fish sausage without added nitrofuran compound may swell considerably from gas formed mainly by *Clostridium*.

Similar spoilage with gas formation can also be observed in products to which considerable shark flesh has been added.

VIII. Chemical Composition

In the 1960 season, routine examination by the Association showed that the average fish sausage contains 67–68% moisture, 14–15% protein, 5–6% fat, and 8–9% starch. This is much less fat content and a little less protein than ordinary meat sausage. Enrichment of the nutritive value of fish sausage with vitamins A or D is reported by certain firms, but assessment of these vitamins has not yet been made by the Association.

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CHAPTER 11

Fish Solubles

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I. Origin and Significance

Fish solubles, as the name implies, are a fisheries by-product containing predominantly water-soluble substances. They are often referred to by the more descriptive name of condensed fish solubles, indicating that condensation or evaporation plays a role in its production. Fish solubles are made from fish stickwater. This is an aqueous extract from cooked fish, usually obtained from fish meal plants, where fish are cooked and separated by pressure into an aqueous extract and fish pulp. The fish pulp is subsequently dried and turned into fish meal. Fish meal plants are, therefore, the main source of raw material for the manufacture of condensed fish solubles. Stickwater exhibits properties which are characteristic of both fish muscle extracts and the gelatin- and glue-containing extracts of bone, cartilage, skin, and other connective tissues. These characteristics change in relative predominance, depending upon whether whole fish or fish offal are being used as raw material for the stickwater.

Prior to 1938, it was customary to discard the stickwater after it had been freed of its content of fish oil. This separation of the fish oil from the stickwater was usually accomplished by passing the stickwater into "settling tanks" where the oil was recovered by letting the oil float to the top, or by passing the stickwater through centrifugal oil separators. The discarded stickwater was often released into surrounding waterways, thereby causing serious pollution and health hazards.

Earlier attempts to utilize the stickwater, and thereby eliminate the pollution problems, had been unsuccessful. These efforts had mainly been directed toward an attempt to recover and utilize the small amount of protein and other nitrogen-containing substances in the stickwater. The cost involved in such a recovery and the products obtained were, however, of such a disappointing nature that further efforts in that direction were abandoned.

The brilliant discoveries in the field of animal nutrition which began during the thirties and continued through the war and postwar period were to a large extent in the vitamin field. During these years, the many B vitamins which now are included in the so-called B-complex group were discovered and isolated, and their physiologic importance was established. The economic significance of this to the farmer and animal-husbandry man was not overlooked. As a result, many known feedstuffs were re-evaluated in the light of these new discoveries, while other, hitherto unknown feedstuffs suddenly became important. The role that fish solubles have played as a source of the B-complex and other growth factors is interesting and important, and will, therefore, be elaborated upon in some detail.

In a report by Wilgus *et al.* (1935) on the properties of protein supplements for poultry and their relationship to the content of vitamin G, mention is made for the first time of fish stickwater as a product containing this important vitamin. The subsequent identification of vitamin G (B_2) with lactoflavin of milk, or riboflavin, and the gradual realization that milk also is a good source of the other vitamin B-complex factors, established milk as one of the best natural, commercially available sources of these accessory food factors. As a result, milk products became the most important vitamin supplement to all well-balanced domestic growth rations.

The outbreak of World War II caused a strong increase in the use of milk products for human consumption, thereby restricting or eliminating altogether the use of milk products as a source of vital riboflavin and the other B-complex factors for animal rations. This situation forced the nutritionists of the feedstuff industry to look for other products with a content of vitamins and other growth factors similar to those of the disappearing milk products. At that time fish stickwater, which Wilgus and others had recognized as a good source of vitamin G, had been further investigated for its nutritional qualities and vitamin content, and had been developed into the product called condensed fish solubles (Lassen, 1940, 1945). This product, which became available from the fish meal plants of California, found increasing favor with the nutritionists and feedstuffs maunfacturers as a replacement for the vitamins and other growth factors of milk, with a resultant increase in demand for and production of condensed fish solubles (Lassen *et al.*, 1951). The yearly production of condensed fish solubles in the United States now exceeds 200 million pounds.

The postwar period brought further clarification of the role the newly discovered vitamins of the B complex played in animal nutrition. The presence of these vitamins and growth factors in important quantities in condensed fish solubles (Berry *et al.*, 1945; Cravens *et al.*, 1945, 1946; Pratt and Biely, 1945; Arscott, 1946; Lassen and Bacon, 1946) aided in establishing this product as an indispensable ingredient in practically all domestic animal growth rations. Recent research has revealed condensed fish solubles to be a good source of vitamin B_{12} (Lewis *et al.*, 1949; Fuller *et al.*, 1952) and of certain unidentified growth factors (Camp *et al.*, 1955). These factors produce favorable growth responses and improvement in efficiency of feed utilization which cannot be explained as being due to any other known nutrient. One of these factors, the so-called "fish factor" (Menge *et al.*, 1953; Jensen and McGinnis, 1956), has recently become important in animal nutrition, and condensed fish solubles seem to be an abundant source of this factor. Another interesting development in the use of condensed fish solubles is the observation that some of the growth-promoting factors may be of inorganic nature (Couch *et al.*, 1955). This extraordinary disclosure is perhaps difficult to comprehend, in view of the predominantly organic nature of the vitamins and the other growth-promoting factors belonging to that general group, but is a timely reminder of the fundamental role that minerals (Burns *et al.*, 1953) and trace minerals play in nutrition. For a detailed discussion of these feeding aspects reference is made to Chapters 8 and 9 in Volume II of this treatise.

II. Composition of Raw Material and Methods of Manufacture

A. Raw Material

The raw material for the manufacture of condensed fish solubles is, as stated earlier, stickwater or presswater, which results from the pressing of whole cooked fish or cooked fish offal during fish meal production. The fish most commonly used for the manufacture of fish meal and, therefore, also for solubles are herring, menhaden, and pilchard. Besides these fish, offal from tuna, salmon, cod, haddock, and various bottom fish are used. In spite of the diversity of species of fish used as raw material, the stickwater resulting from the processing seems to be fairly uniform in appearance and composition. A typical analysis of some of the main constituents of stickwater shows the following values:

Total solids	5.6%	Ash	0.95%
Protein (N × 6.25)	3.5%	Fatty substances	0.6%

B. COOKING

The type of equipment used in the fish meal plant and the manner in which it is used can, however, have some influence upon the total solids content of the stickwater. If, for instance, an excess of live steam is used in the "cooker" in which the fish are cooked, a dilution of the stickwater will occur, and the total solid content will be correspondingly reduced. It often happens, also in fish production that water is added to the stickwater to secure a more complete oil separation and recovery; this naturally also reduces the solid content of the stickwater. The gradual replacement of the "live-steam cooker" by the steam-jacketed cooker and the change-over from oil-settling tanks to centrifugal oil separators have now largely eliminated these sources of dilution of stickwater.

The fatty matter in stickwater, usually present as minute globules in a high state of dispersion, contains an appreciable amount of phospholipids. The nitrogen-containing substances in the stickwater consist largely of noncoagulable, water-soluble proteoses, peptones, extractives such as creatin, carnosine, anserine, and urea, plus small amounts of amino acid. A very small part of the total nitrogen in the stickwater is usually present also in the form of highly dispersed protein particles. These particles, together with the oil particles referred to above, give the stickwater an opaque or milky appearance. The addition of a flocculant like aluminum sulfate or a change in the pH of the stickwater will precipitate these suspended particles, leaving a clear, yellow, supernatant liquid. This clear liquid in its appearance, taste, and composition has much in common with soup of extract made from beef. It has been found, however, that carnosine, one of the imidazole compounds characteristic of beef extract, is present in stickwater in only relatively small amounts, while a chemically similar substance, anserine, is present in fairly substantial quantities. Upon standing, particularly at temperatures below room temperature, stickwater prepared from freshly caught fish often sets into a gel.

C. OIL REMOVAL

The amount of stickwater which may be recovered from fish meal operations varies usually from 150 to 220 gallons per ton of raw fish, depending, as already mentioned, upon whether the cooking of the fish has been done by direct or indirect steam cooking. The procedure followed for the further treatment of stickwater may vary considerably. With stickwater from fatty fish, such as herring, menhaden, and pilchard, a thorough separation of the fatty matter from the stickwater is necessary to make it suitable as raw material for condensed fish solubles. In addition, the price of the oil recovered is usually such that this becomes an economically attractive step. With stickwater from nonfatty fish, the oil content of the stickwater if often so low that the question of whether the recovered oil will pay for the cost of separaion is involved. In such instances, considerations other than cost of oil recovery must be given preference, since good quality condensed fish solubles cannot be made from stickwater with a high oil content. Generally speaking, a stickwater which is to be used for solubles should have an oil content of not more than 0.5%. In order to better remove the last amount of fatty matter and suspended proteinaceous matter, the stickwater is often treated with small amounts of an acid, thereby permitting the production of a more stable condensed fish solubles of lower viscosity. If acid is used, the pH is usually lowered to about 4.5.

The temperature of the stickwater as it comes from the fish press is very close to 212°F. As it passes through the oil centrifuge or settling tanks, the temperature is generally kept up as close as possible to 200°F. to obtain a better oil separation. After the oil has been separated, the stickwater is usually pumped into storage tanks where the temperature is kept up, because a loss of temperature at this point will have to be made up for by the use of extra steam in the subsequent concentration of the stickwater in the evaporators. There is, however, another reason for not letting the temperature of the stickwater go down. It has been found that spoilage of the highly perishable stickwater does not occur at temperatures above 185°F., whereas at temperatures of 165°F. and below spoilage of the stickwater proceeds at an increasingly faster rate, thereby producing foul odors and causing losses of nitrogenous substances and other undesirable changes. The problem of spoilage and temperature control is, of course, eliminated if acidulation is used.

D. CONCENTRATION

The next step in the manufacture of condensed fish solubles is its concentration in suitable evaporators from a total solids content of approximately 5% total solids to approximately 50% total solids content.

This requires roughly that 90 lb. of water be evaporated from every 100 lb. of stickwater. The average United States fish meal plant, when operating, produces large quantities of stickwater per hour. To keep up with such a production, large and efficient evaporation facilities are necessary. The evaporation or condensation of stickwater into condensed fish solubles is, therefore, considered a most important and critical step, both from the point of view of cost of operation and type of equipment, as well as from the point of view of the influence that the method of concentration can have on the physical and biological properties of the finished product.

It is a well-recognized fact that stickwater contains desirable biological growth factors, some of which are relatively thermostable, while others are thermolabile. The rate at which these last factors may be destroyed in the processing of the stickwater is a function of both the temperature to which they are heated and the time at which they are kept at an elevated temperature. Considerations such as these would make a processor of condensed fish solubles want to concentrate his stickwater at as low a temperature as possible and have the stickwater exposed to this temperature as short a time as possible. All these considerations, in regard to both thermal sensitivity of the product and cost of operation, can be satisfied to a large degree by the use of multiple-effect vacuum evaporation equipment. The principle of multiple-effect vacuum evaporation is now a little more than one hundred years old. By this method a liquid to be evaporated is evaporated in a closed steam pan, and the resultant water vapor (steam) is led into the jacket or steam chest of a second, closed steam pan where it gives off, by condensing, all its heat of evaporation, thereby helping to evaporate some more liquid contained in the second pan. To do this, the liquid in the second pan must be made to boil at a lower temperature than the temperature of condensation of the steam from the first steam pan. This lowering of the boiling point of the liquid in the second pan is accomplished by keeping it under a suitable vacuum, thereby lowering the temperature enough to create a flow of heat from the condensing steam in the jacket or chest into liquid in steam pan number two.

By adding several pans in series and connecting them as described, and maintaining an increasingly high vacuum in each succeeding pan, it is possible to lead the liquid to be evaporated from one pan (or effect) to the next one and obtain a very effective evaporation, at a relatively low temperature and at a very great saving in steam. The addition of several vacuum pans (effects) with their auxiliary equipment, instead of one large vacuum pan, naturally increases the cost of the installation. It is, therefore, a rare sight to see multiple-effect installations consisting of more than four effects. At this number of effects, the savings in steam which may be made by adding another effect are usually offset by the extra cost of additional equipment. Most of the evaporation plants for stickwater are, therefore, triple- or quadruple-effect installations. That the saving in steam consumption by the use of the multiple-effect evaporation system is considerable is best demonstrated by keeping in mind that it takes a little more than one pound of steam to evaporate a pound of water in an ordinary atmospheric evaporator, while the evaporation of one pound of water in at triple-effect evaporator requires only about 0.4 pound of steam. Inasmuch as steam constitutes by far the major item of cost in the production of condensed fish solubles, it is understandable why the multiple-effect evaporation system is being used practically everywhere for the manufacture of condensed fish solubles, in spite of the higher cost of equipment. While the multiple-effect evaporation principle is generally used for the concentration of stickwater, there seems to be a considerable variation in the method of operation and design of the individual vacuum pan and its auxiliary equipment.

In regard to the method of operation, the stickwater is usually introduced continuously into the first effect and, as evaporation proceeds, is allowed to flow slowly into the following effects, through an interconnecting feed-pipe system. The higher vacuum which has to be maintained in each succeeding effect, and which is the basis for the multiple-effect evaporation principle, provides the moving force for this flow. By adjusting the valves inserted in the interconnecting feed-pipe system, it is possible to regulate the rate of flow of evaporating stickwater from one effect to the next so that evaporation conditions in each effect remain at their optimal level, and so that the stickwater, when sufficiently concentrated, may finally be withdrawn from the last effect. The condensed fish solubles may be withdrawn either continuously or intermittently. In either case, the higher vacuum which usually exists in the last effect and the nature of the finished product require special pumping equipment. In case a continuous withdrawal from the last effect is used, the discharge pump may be connected with, and controlled by, a specific gravity-measuring device involving a hydrometer which permits a discharge only of condensed fish solubles of a given specific gravity, and, therefore, roughly of a given total solids content.

While specific gravity measurements are generally preferred as an approximate indication of the total solids content of the stickwater in the last effect, refractive index measurements can also be used for fast solids determinations. A sampling device attached to the last effect, the so-called "try box," permits the operator to withdraw samples for testing purposes. A specific gravity of approximately 1.2 indicates that the stickwater has come up to near the 50% total solids which is standard for condensed fish solubles. The variable fat content of some condensed fish solubles and its collodial nature make specific gravity determinations, if done by hydrometer, inaccurate as a measure of total solids content; this disadvantage is overcome, in part, by pumping the finished product to a storage tank large enough to compensate for variation in total solids content of the individual run. The direction of flow of the stickwater through the various effects of the evaporation plant, as described above, identifies this flow as the so-called forward-feed method. This is the method most commonly used. There may, however, be instances where a backward feed or a mixed feed would be advantageous. In so-called mixed feed, the stickwater could be introduced into the second effect, flow into the third effect, and from there be pumped into the first effect. In this instance only one extra pump would be required to bring the stickwater from the higher vacuum in the third effect into the lower vacuum of the first effect. The advantage of this type of feed is that condensed fish solubles having a negative viscosity temperature coefficient, would reach their final stage of concentration in the effect which evaporates at the highest temperature. This method of feeding can save steam in instances where the temperature of the feed has not been kept up.

Due to its perishable nature, stickwater often contains a considerable amount of so-called noncondensable gases. This becomes particularly noticeable in instances when stickwater has not been acidulated or, if not acidulated, has been allowed to stand for some time before it is concentrated. Upon cooling, thermophilic microbes may sometimes cause decomposition of the protein and other nitrogenous matter (decarboxylation) whereby CO_2 and other gases are released. As mentioned earlier, this decomposition can be considerable even at temperatures as high as 170°F. By lowering the pH of the stickwater, by the addition of acid, or by maintaining the stickwater at a temperature of about 190°F. or above, this very undesirable deterioration can be largely avoided. The multiple-effect evaporators are, therefore, provided with means to eliminate the undesirable noncondensable gases. Failure to do so would soon bring the efficiency of the multiple-effect evaporators down to a small fraction of their normal performance capacity. This reduction in efficiency of the evaporators is due to the accumulation of noncondensable gases in the steam chests or steam space of the second and third effects, thereby blanketing the heat-transfer surface and reducing or eliminating evaporation. By venting the steam chest or steam space directly into the corresponding evaporator or into the condenser, it is possible largely to eliminate the detrimental influence of the noncondensable gases. The proper control of air venting is accomplished by adjusting the vent valves and requires the experience of a skilled operator. An excessive venting will waste useful steam and, therefore, reduce evaporation efficiency.

E. Type of Evaporator

The evaporators used in the multiple-effect evaporation system for stickwater are restricted to a few types. The most commonly used types are (1) the horizontal-tube evaporator, (2) the vertical-tube evaporator, (3) the inclined-tube evaporator, and (4) the forced-circulation evaporator.

The horizontal-tube evaporator is simple in design, and as its over-all thermal efficiency seemingly equals that of the other types, it has retained its popularity through the years. It has a vertical cylindrical or rectangular shell to which are attached two steam chests. Into these are built two tube head sheets, where the ends of the evaporation tubes are secured. The steam, when introduced into the steam chest, flows inside the tubes, thereby transferring its heat energy through the tube walls into the surrounding stickwater.

The vertical-tube evaporator is usually cylindrical and contains a downtake opening in the center of the heating element. In this type of evaporator the steam surrounds the outside of the heating tubes, causing the heat to flow through the tube walls into the stickwater which circulates through the tubes in an upward direction. This type of evaporator can be built in larger units than the horizontal tube evaporator, and is probably the most commonly used type of evaporator.

The inclined-tube evaporator is also cylindrical in form and similar in its heat-transfer characteristics but has its heating element inclined outside the evaporator proper to secure a better circulation of the stickwater and, thereby obtain higher heat-transfer coefficients. The heating element is usually longer than that of the vertical-tube evaporator. In all of the three evaporator types described above, a satisfactory heat transfer from steam to stickwater has depended upon the natural velocity of the stickwater set up be convection currents, and the explosive force caused by the evaporation. The over-all heat-transfer coefficients obtained by such means are usually low.

The forced-circulation evaporator type has a vertical heating element consisting of tube bundles through which the stickwater is forced at high velocity, thereby obtaining much higher heat-transfer coefficients. The performance of this type of evaporator is excellent, but the cost of forced circulation and the wear on the circulation equipment offset, to some degree, the high performance qualities of the forced-circulation evaporator.

Common for all the types of evaporators described here is that, in order to obtain maximum evaporation performance, the heat-transfer surfaces must be absolutely clean. Unfortunately, stickwater has a tendency to coat the heat-transfer surfaces with a film which, as it thickens, can reduce the evaporation performance of the evaporator very spectacularly. This reduction in evaporation performance due to coating applies not only to heat-transfer tubes in the first effects, but may even appear in aggravated form in the subsequent effects, where one side of the heat-transfer surface may be coated with stickwater, while the other side is coated with a black spongy layer, presumably resulting from the interaction between the condensable vapors and the metallic surface. With poor pretreatment of the stickwater, or with careless handling of the evaporators, the loss due to coating of the heat-transfer tubes, inside as well as outside, can become a major factor in the economy of the evaporation.

Evaporators suitable for stickwater processing have been made of steel, cast iron, or stainless steel. Of these three materials, stainless steel is undoubtedly the preferred material, but also the most costly. Cast iron, with a high silicon content, is a very suitable material and has better resistance properties against corrosion than has, for instance, plate steel. The heating tubes may be made from any one of several of the metals or alloys with good heat-conductivity properties. Copper tubes may be used, although they do not seem to stand up well against stickwater in the long run. Admiralty brass tubes combine high heat-conductivity properties with good resistance to corrosive attack from stickwater. Stainless steel tubes are much used because of their very high resistance to corrosive action by the stickwater, and this fact seems to offset their lower heat conductivity properties and their much higher cost.

F. Auxiliary Equipment

The auxiliary equipment necessary for the successful operation of a multiple-effect stickwater evaporation plant is relatively simple. Pumps are required to evacuate the steam condensate from all the effects except the first, where steam usually is introduced under pressure, and the condensate may, therefore, be evacuated through an ordinary steam trap device. These pumps, which must be able to evacuate the condensate against a vacuum, are usually slow-motion reciprocating steam pumps or self-priming centrifugal pumps.

The so-called Magmapump which evacuates the heavy semiviscous condensed fish solubles from the last effect, against a vacuum of approximately 28 in., is a long-stroke, slow-speed plunger pump with 4 suction valves.

The vacuum system necessary for multiple-effect evaporation is simple. The vacuum is supplied to the condenser into which the vapors from the last effect condense. The vacuum may be produced by any of the several types of vacuum pump, or by a steam ejector. The condenser is often a barometric condenser, where the vapors from the last effect are condensed by meeting the cooling water cascading down through the condensor into the barometric leg. Other types of vacuum condenser, such as jet condensers and wet condensers, have also been used successfully in stickwater evaporators. The barometric condenser seems, however, the preferred one for medium and large installations. Vacuum gauges must be provided for each effect. Thermometers to measure temperatures not only in the boiling liquid of the various effects, but also in their steam chests or heating elements are necessary. Liquid-level sight glasses in each effect are indispensable for good control of the evaporation of stickwater. The enormous influence that liquid level has on rate of evaporation in most of the type of evaporators used for stickwater is not always fully recognized. Several sight glasses, which enable the operator to watch the actual boiling inside the evaporators, are indispensable. All the effects should be provided with vacuum breaks of large enough diameter to cause a fast change in vacuum when opened. This is of importance in several instances during the start and finishing of the evaporation and becomes particularly useful if the stickwater, as sometimes happens, has a tendency to foam.

G. STEAM CONDENSATE

Finally, a word about the steam condensate which results from the evaporation of stickwater in multiple-effect evaporators. The condensate from the first effect is normally uncontaminated and may, therefore, be returned to the steam plant and used for boiler feed. The returned condensate from the first effect is, of course, equal to, or, under practical working conditions, nearly equal to, the amount of steam supplied to the first effect. The condensate which is being continuously pumped from the second and higher effects is usually sufficiently contaminated to make it unfit for boiler feed. The contamination is due to the entrainment of droplets of stickwater in the vapors which during evaporation next. The installation of entrainment arrestors or "catchalls" in the are carried from one effect into steam chest or heating element of the large vapor ducts connecting the effects has reduced the degree of contamination, but has not eliminated it. The condensate also contains a certain amount of condensable gases, which the ordinary catchall device does not trap. The condensate from the second and succeeding effects is, therefore, usually run to waste, unless a use can be found for it in process heating.

III. Quality of Condensed Fish Solubles

To fully appreciate the biological qualities of condensed fish solubles, it is necessary to evaluate them in terms of the response they give in animals. In such tests the condensed fish solubles are incorporated into suitable rations and fed to growing, producing, or breeding animals, all depending upon what biological quality the solubles are tested for. With suitable controls, and large enough groups of animals, the performance of the solubles may be ascertained with fair accuracy. Such tests are, however, expensive and usually take a long time to complete. It is, therefore, customary, once the general qualities of the solubles have been established, to limit any further testing and evaluation to simple chemical or microbiological tests for such entities as, in the opinion of the analyst, the producer, or the consumer, may characterize the product with sufficient accuracy.

The biological qualities of condensed fish solubles have been discussed earlier in this chapter. In what follows, an account will be given of what chemical and microbiological assays have revealed in regard to the composition of condensed fish solubles, and of what conclusions might be drawn, with respect to quality or mode of manufacture, from such assays.

A. General Characteristics

The condensed fish solubles produced by the method outlined in the above, are a brown, somewhat viscous liquid with a mild fishy odor. These physical characteristics, including the aroma, vary considerably, depending upon the freshness of the stickwater raw material, individual methods of manufacture, and seasonal characteristics of the fish from which the stickwater is made. Differences in the species of fish used for raw material seem of less influence upon the final characteristics of the solubles. The commercial grade of condensed fish solubles usually contains 50% total solids and has, at room temperature, a specific weight of approximately 1.2.

A typical analysis of some United States West Coast condensed fish solubles is given in the tabulation below.

Total solids	50.25%	pH	4.5
Fat	4.32%	Specific gravity (approx.)	1.2
Ash	9.17%		
Protein (N × 6.25)	33.65%		

This analysis, which usually is carried out in conformity with methods recognized and recommended by the Association of Official Agricultural Chemists, does not reveal the more interesting details with regard to the actual composition of the condensed fish solubles. The protein content is, as indicated, obtained by multiplying its nitrogen content by the commonly accepted factor of 6.25. There is much evidence that this conversion factor does not reflect an accurate picture of the true protein content of several fisheries products, including condensed fish solubles. Fish muscle contains a fairly substantial amount of so-called nitrogenous extractives. In fish meal operations these extractives appear to a large extent in the stickwater. Upon concentration of the stickwater into condensed fish solubles, all solids, the nitrogenous extractives included, are concentrated tenfold. These extractives, which may account for 10 to 20% of the total nitrogen content of the solubles, are not considered good sources of protein. They may be divided into the following general groups (Shewan, 1951):

1. Volatile bases, including ammonia, mono-, di-, and trimethylamines
2. Trimethylammonium bases, e.g., trimethylamine oxide and betaines
3. Guanidine derivatives, such as creatine and arginine
4. Imidozole derivatives, such as histidine, anserine, and carnosine
5. A miscellaneous group consisting of urea, amino acids, and purine compounds

Of these compounds, some of the volatile bases will presumably have been removed during the vacuum concentration, but may appear later on if the solubles should be subject to spoilage. The balance of the nitrogen in condensed fish solubles is protein nitrogen and accounts, as already indicated, for 80% or more of the total nitrogen. These proteins consist mainly of non-heat-coagulable, water-soluble proteoses which, although not complete proteins in the nutritional sense of the word, may have good supplemental value in certain feed rations. The small amount of condensed fish solubles generally used as a vitamin supplement in feed rations (1–4%) is, however, such that the question of protein quality of the solubles becomes generally insignificant.

B. Content of Major Constituents

Analyses of several of the amino acids in condensed fish solubles have been made. The analysis shown in Table I reflects the average content of some of the more important amino acids in West Coast condensed fish solubles.

A vitamin analysis reveals, in part, the reason why condensed fish solubles have attained such prominence in the field of animal nutrition.

TABLE I

AMINO ACID ANALYSIS CONDENSED FISH SOLUBLES

Amino acid	% Crude protein (N × 6.25)	Assay method	Amino acid	% Crude protein (N × 6.25)	Assay method
Arginine	4.84	Mb.[a]	Tryptophan	0.35	Mb.
Histidine	5.79	Chem.[b]	Methionine	1.51	Mb.
Lysine	4.87	Mb.	Threonine	2.55	Chem.
Leucine	4.67	Mb.	Cystine	0.58	Chem.
Isoleucine	2.73	Mb.	Glutamic acid	8.44	Chem.
Phenylalanine	2.33	Chem.	Proline	6.70	Chem.

[a] Mb = microbiological.

[b] Chem. = chemical.

An average of the vitamin values characteristic of West Coast fish solubles shown in following figures:

Vitamin	µg./g.	Vitamin	µg./g.
Riboflavin	22	Pyridoxin	12.5
Pantothenic Acid	84	Choline	1100
Thiamine	7.5	Folic Acid	0.23
Niacin	390	Vitamin B_{12}	0.47

While these analyses give a good picture of the content of these accessory food factors, the other growth factors (fish factors), for which no quantitative assay has yet been developed, will have to wait for further work in their identification and analytical determination before they can be classified with above-mentioned vitamins, if, indeed, they prove to be vitamins.

The ash content is considerable, and varies within rather narrow limits when the solubles are made from fresh stickwater. An ash content of from 8.5 to 9.5% should be normal for condensed fish solubles of 50% total solids. A typical analysis of the ash constituents is given in the tabulation below.

Constituent	%	Constituent	%
Potassium (K)	1.93	Iron (Fe)	0.0249
Sodium (Na)	1.87	Magnesium (Mg)	0.016
Phosphorous (P)	0.85	Copper (Cu)	0.007
Calcium (Ca)	0.0869	Iodine (I)	0.007
Manganese (Mn)	0.0869	Aluminum (Al)	0.005
Total ash		8.86%	

It will be noticed that potassium and sodium appear in the ash constituents in considerable amounts, and in about equal parts, and that the other elements, such as copper, iron, manganese, and iodine, are all present in large enough quantities to be of physiological importance when the condensed fish solubles are incorporated into a ration in the amounts normally used. Besides the above-mentioned elements, a spectrographic examination has revealed the presence, in trace amounts, of cobalt, molybdenum, and boron. The recent discovery by Couch *et al.* (1955) and others that the ash constituents of condensed fish solubles have growth-promoting qualities makes the effort to secure a more complete analysis of the ash components and their role in animal nutrition of particular importance.

C. QUALITY CONTROL

The following analytical procedure has been found of particular value in determining the quality of condensed fish solubles and whether they have been made from fresh stickwater.

A high content of ammoniacal nitrogen in the condensed fish solubles indicates spoilage either of the stickwater raw material or of the condensed fish solubles after they have been produced. A high ash content may also be an indication of spoilage or adulteration. A high free fatty acid content of the fatty matter contained in the solubles is usually a reliable sign that the stickwater raw material was spoiled before concentration into solubles. In Table II are given values for ammoniacal nitrogen, ash, and free fatty acids of the fatty matter contained in several samples of 50% total solids condensed fish solubles, which were produced from a 2,000-gallon tank of originally fresh stickwater after it had stood for 0, 24, 48 and 96 hr. respectively (Lassen *et al.*, 1949).

TABLE II

CHANGE IN COMPOSITION OF CONDENSED FISH SOLUBLES AS INFLUENCED BY DEGREE OF FRESHNESS OF STICKWATER

Composition	0 hr.	24 hr.	48 hr.	96 hr.
Ammoniacal nitrogen in % of total nitrogen	0.21	0.85	2.72	2.99
Ash in %	8.43	8.75	10.3	13.5
Free fatty acids of fatty matter in % as oleic acid	25.75	38.38	170.0	128.3

The trend of these values is quite pronounced. The rise of the fatty acid above 100%, as shown in Table II, means that the fatty acids are present in units generally smaller than the oleic acid. An ash content in solubles of higher than 9.5% based on a 50% total solids content, may indicate either spoilage or adulteration of the solubles with substances high in ash, such as salt or sea water. If spoilage is suspected, the high content of ammoniacal nitrogen and the high free fatty acid content of the fatty matter in the solubles will confirm it. If, on the other hand, it is adulteration with sea water or salt which is involved, a determination of the sodium-potassium ratio in the ash constitutents may show it. In normal condensed fish solubles, the sodium-potassium ratio is close to 1:1. In sea water, the sodium-potassum ratio is 1:27 A relatively small amount of sea water added to the stickwater would alter the sodium-potassium ratio in favor of sodium, as would the addition of any sodium compound with a wide Na:K ratio. It is often found useful to determine the fraction of total nitrogen in condensed fish solubles, which is insoluble. This determination gives information as to the degree to which the stickwater has been freed of suspended protein before it was concentrated. A high content of water-insoluble nitrogen compounds (protein) is undesirable, as it tends to increase the viscosity of the solubles, thereby making them more difficult to handle. There is also evidence that solubles high in insoluble particles spoil more readily.

The maintenance of a proper pH in the condensed fish solubles is of great importance as a means of preserving the quality of the product. Due to their composition, condensed fish solubles are a good medium for the growth of microbes. The average storage facilities for condensed fish solubles are usually such that microbial access to the solubles cannot be prevented. By maintaining the solubles at a pH of about 4.5, spoilage may be largely prevented. Failure to do so results in a progressive decomposition of the solubles with the development of noxious gases, and an increase in the pH value, ammoniacal nitrogen, and ash constituents will result.

IV. Storage and Transportation

A. STORAGE

Condensed fish solubles may be stored in steel or redwood tanks. The individual tanks are usually so large that they can hold several days' production, thereby allowing the processor to equalize any deviation from the standard 50% total solids content which may occasionally occur during manufacturing operations. Many of these tanks are provided with circulation facilities to aid in the blending of the solubles and thus prevent stratification.

Most condensed fish solubles nowadays are sold in tank-car lots of 75,000 to 80,000 lb. Some feedstuff manufacturers who buy solubles in smaller lots prefer to receive them in steel drums or oak barrels, in which they are held until used, thereby avoiding the necessity of providing storage tank facilities at their mixing plant.

For larger feed mills, however, storage tank facilities for condensed fish solubles are necessary. These tanks are usually made of riveted or welded steel plate. In some instances, wooden tanks or even reinforced concrete tanks are used. Wooden tanks, though often less expensive than steel tanks, are difficult to keep clean; and reinforced concrete tanks, in order to be used for condensed fish solubles storage, must be coated on the inside surfaces with an impervious layer of bitumastic paint or other equally satisfactory protective coating material.

B. Transportation

When a tank car of solubles arrives at the feed mill, it is usually unloaded by connecting it with the unloading riser by means of a flexible hose through which the solubles are drawn by pump to the storage tank. Steam facilities for the heating of the coils in the tank car are desirable in regions with low winter temperatures, as the viscosity of condensed fish solubles increases noticeably at lower temperatures. The pump used for the unloading is usually a 2- to 3-in. gear pump with capacity of 50 to 100 gallons a minute. A strainer of suitable design is often inserted in the pipeline ahead of the pump. A relief valve on the pressure side of the pump is also recommended. The storage tanks for holding the condensed fish solubles at the mill are very similar to those in the tank yard of the producer, but generally smaller. They should be fully closed with a breather pipe of gooseneck design to prevent dust and moisture from entering the tanks. Some method for agitating the tank content is desirable.

C. Mixing Operations

The addition of condensed fish solubles to a dry feed mix, as is done in feed mills, presents problems very similar to those encountered when molasses is added to feed rations, and, generally speaking, equipment of this type is used. Most modern feed mills in the United States have this equipment, and where it is lacking, it can be readily installed. The importance of securing an adequate distribution of the solubles in the mixer cannot be emphasized too strongly; this is often accomplished by spraying the solubles in proper proportion through nozzles into the rapidly moving dry feed in the mixer. Advice on how to accomplish this in a satisfactory manner is usually supplied by the manufacturers of the feed-mixing equipment or by the manufacturers of the condensed fish solubles.

V. Specifications of Identity and Quality

Quality specifications for condensed fish solubles are generally very simple. A total solids content of 50% is usually required, and in some instances a maximum fat content is insisted upon. A high fat content in solubles is often objected to by certain feed manufacturers because of color changes and other changes which it may impart to the feed with which it is mixed. No specifications in regard to vitamin content or ash content have as yet become customary; neither have specifications as to species of fish from which the solubles have been produced become common. In the United States, it is generally assumed that East Coast solubles and Gulf Coast solubles are made from menhaden, while West Coast solubles are from either tuna, sardine or mackerel, or a mixture of any of them. British Columbia or Alaskan condensed fish solubles are assumed to be from herring or predominantly so.

In a tentative purchasing guide prepared by the Nutrition Council of the American Feed Manufacturers Association appears the following definition of condensed fish solubles:

"Condensed Fish Solubles is the product obtained by condensing the aqueous portion of the mixture resulting from pressing the oil from the fish."

This definition is unfortunate in that it gives the reader the impression that stickwater results from efforts to press oil out of raw fish. Neither oil nor stickwater can be pressed out of fish, on a practical basis, unless the fish has been cooked and its protein denatured. The denaturation of the fish protein is the fundamental step involved in making stickwater available, and is independent of whether or not oil is present in amounts large enough to recover. In the cooking and subsequent pressing of fish in the fish meal plants, approximately 60% of the total weight of the fish goes into the aqueous portion.

It would seem that the popularity and large sales which condensed fish solubles enjoy, both on a national and international scale, would demand more comprehensive standards for both their identity and their quality.

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CHAPTER 12

The Regional Development of Fisheries and Fish Processing

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I. General Survey

Chapter 7 of Volume II by the senior author described the role of fish in world nutrition in general and in specific areas. Chapter 18 of that volume outlined the major discernible trends in the utilization of fish on both global and regional bases. This chapter aims at surveying the actual happenings in technical and industrial respects with reference to commercial developments in individual countries.

The world's fish industry is experiencing an expansion without precedent in human history. Endeavors were conspicuously successful in the creation of the large Peruvian fish meal industry, based on organizing a fish catch now exceeding that of the Soviet Union. Another noteworthy happening is the growth of tuna processing from a prewar catch of 200,000 metric tons to a figure now exceeding 0.5 million tons. Third, freezing and filleting have made extensive inroads into a great number of countries.

Owing to the immense discrepancies between the technically advanced countries and those less advanced in this respect, it seems most conducive to a lucid understanding of present developments in the fish-processing industry to analyze each region separately.

To facilitate discussion of these regions, the countries involved are listed at the beginning of the section. However, since some countries border more than one area and since the statistics may not be given by regions, the country will be discussed in the section where the major portion of the catch is landed, with a few exceptions.

II. Northeast Atlantic—Europe

NORWAY

The fisheries off the coast of Norway may be some of the oldest in the western world. The hardy Norsemen probably were primarily fishermen and explorers later. Cod and herring form the bulk of the catch. The Lofoten fishery off the coast of northern Norway is one of the richest cod fisheries in the world. During the peak winter season as many as 20–30,000 fishermen with 4,000 boats have fished there. Other fishing grounds are the Icelandic Banks, Faeroe Banks, banks in the Barents Sea and off Bear Island and Spitsbergen. Norwegian fishermen regularly fish in the Davis Strait and the Grand Banks. In addition, Norway does considerable whaling in the Antarctic, but this fleet is being reduced.

TABLE I
NORTHEAST ATLANTIC-EUROPE FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Norway	1,152.5	1,504.0	1,812.9	1,598.9	1,509.4	1,338.0
Denmark	97.1	225.9	376.0	581.2	637.4	784.9
U.K.	1,198.1	1,206.1	1,097.5	923.8	902.7	944.4
Ireland	12.8	25.8	21.4	42.8	32.2	29.0
Netherlands	256.2	294.1	334.0	314.7	346.0	321.9
Belgium	42.8	71.1	75.7	63.7	61.7	59.9
France	530.3	437.5	563.3	710.0	720.0	737.0
West Germany	776.5[a]	408.7	761.2	674.0	618.9	632.7
Iceland	327.2	478.1	453.5	592.8	710.0	832.6
Faeroe Islands	63.0	92.3	94.4	109.4	120.1	143.5
Greenland	4.7	21.0	25.2	34.6	41.8	—

[a] All Germany.

Cod is caught all along the Norwegian coast. One of the oldest fish products is stockfish, which is dried unsalted fish, mainly cod. In 1961 Norway produced 35,200 metric tons of this item, over 70% of the world total. Stockfish is even better than salted cod in the humid tropics since it has no salt to absorb moisture from the air. In the same year almost as much (34,900 metric tons) salted cod was produced. Norwegians usually process most of their salted cod by a special dry-salting method to produce klipfish. Norway is also one of the main producers of cod-liver oil.

The herring fishery is, however, more important than that of the cod. The herring group accounts for one third of the total catch, and cod fishes another third. In 1956 the percentages were 62.7 and 27.4, respectively. These changes are due to the fluctuations of the herring catches. One would expect considerable waste unless adequate provisions were made to process excess fish. Consequently a fish meal industry has been developed. In 1960 almost half (48.9%) the herring catch was processed in reduction plants.

Of the herring used for food 38% is salted, 24% frozen, 7% spiced and marinated, 3% smoked, and the rest canned. The so-called canned herring consists of a number of smoked products, such as kippered herring, small herring, and sprats. Sprats have been canned at Stavanger, the center of the fish-canning industry, ever since 1878. Herring products make up the bulk of the fish pack.

Like most leading fishing countries, Norway has shown a notable increase in the production of frozen products. From 1950 to 1958 frozen fillets increased 2.5 times; in the same period frozen herring increased over 4 times.

In recent years, salted lingcod has been giving salted cod stiff competition on the Cuban market. Brazil is Norway's largest customer for salted cod. In 1961 Norway earned more money from the export of fish and fish products than any other country except Japan. Norway has a growing industry in supplying salted herring roe to Japan, where it is made into "kazanoko" which is consumed in quantity during the Japanese New Year celebrations.

DENMARK

The Danes have long depended on fish as a staple item of the diet. The Danes have further developed fisheries in the waters around the Faeroe Islands and near Greenland.

One third of the catch is herring and related fish, another third belongs to the cod group. Mullet comprises one tenth of the catch and flounder slightly less.

Over half (56%) of the nation's food fish (22.7% of the total catch) is consumed unprocessed. Half the total catch is used for reduction. Besides the offal, part of the herring and certain species formerly discarded or not captured earlier, as the sand launce, are processed into meals. Miscellaneous uses, such as fish silage, account for 9.4%.

Between 1948 and 1961 the volume of fish frozen almost quadrupled, while the percentage of food fish frozen doubled. This expansion has affected fresh-market sales and the amount of fish cured and canned, all showing declines. Frozen white fish fillets have become an important item of export. Freezing facilities in Greenland have been expanding in the last few years.

The main product of both Greenland and the Faeroe Islands is still, however, cured fish. In Greenland, more than four fifths of the catch is cod. Approximately three fourths of the cod is salted and most of the rest goes for stockfish production. About 3.5% is filleted and exported, but nearly 7 times more catfish is filleted. Shrimp, most of which is frozen and exported, forms the major portion of the remaining catch.

In the Faeroe Islands, about the same proportion of the total catch is cod. About 84% of fish is cured, mainly by salting. Haddock is about the only species canned; in 1962 this amounted to only 44 metric tons fresh weight. Besides the offal, less than 1000 tons are ground into fish meal.

Young herring is usually processed in oil or tomatoes and labeled sardines. The canning industry has developed several specialties, such as "caviar" from lumpfish roe, smoked cod livers, and cod roe.

A thriving industry has developed in Denmark: the raising of rainbow trout for export, mainly to England and the U.S. Cultivation is centered around Jutland.

UNITED KINGDOM

The fisheries in the North Sea and around the Shetland and Hebrides Islands have been known since prehistoric times. The British have visited Icelandic waters since at least the tenth century. Just when they discovered the Newfoundland Banks may never be known.

Two thirds of the catch is cod and related fish and one tenth herring. Four fifths of the catch is consumed unprocessed; one tenth is frozen; minor quantities go for reduction, curing, canning, and miscellaneous purposes.

Cod is largely distributed unprocessed or frozen. Unlike most continental European countries, salt cod was never very popular. Conversely, almost nine tenths of the herring catch is processed in some way, over one eighth quick-frozen, one twelfth canned, one fifth for meal and oil, one seventh for pet food, and the rest cured. Some special products are well known: kippers make up 11.5% of the total, of which 3.5% is processed into red herring, 1.5% marinated, and 1% klondyked.

Smoking

Smoking is the most popular processing method in the U.K. today. Kippered herring and finnan haddie are almost as synonymous with the English way of life as tea and crumpets. There has been a 60–70% decline in the postwar period in the consumption of both these items, possibly due to poor quality control in manufacture. An effort is being made to increase their popularity by using good quality raw material.

Both haddock and cod fillets are smoked. Bloaters and bucklings are produced for home consumption, but most of the red herring is exported to the Mediterranean region. Aside from "smokies" made from undersize haddock, almost all other fish are cold smoked. Mildly smoked salmon is a delicatessen item. Cod roe is smoked after being fairly heavily salted.

Other Methods

Salting has also declined in volume in recent years. Canning has never been of great importance in the U.K. fish industry. Cod roe and fish pastes make up a minor portion of the pack. The chief pack is herring or pilchards in tomato sauce, most of which is exported to Australia. Kippers are also canned. By far the largest pack is pet food, mostly canned, but some is dehydrated.

The offal and excess fish are processed into meal, oil, and solubles. A comparatively new industry, the collecting and processing of seaweeds for alginate, shows considerable promise in the Hebrides.

IRELAND (EIRE)

The Irish have been basically an agricultural people. Nonetheless fisheries have also emerged. The deep-rooted Catholicism of the nation has been an important factor in the regular inclusion of fish in the diet. The great number of fishing ports along the coast has not been conducive to rapid development of a large-scale fish-processing industry. Plans have been developed for the construction of eight major harbors geared for the export trade.

Most fisheries are restricted to coastal shore waters, particularly in the numerous bays; some fishermen go out into the Irish Sea. A little less than half the total catch is herring; molluscs comprise one tenth.

It is not surprising that over four fifths of the catch is eaten fresh. Curing accounts for one eighth. The remaining fish is frozen or processed into meal or oil in about equal proportions.

The government has recently been trying to stimulate interest in the expansion of the fishing industry. Danish capital has been backing a trout-rearing venture in western Ireland. The trout are frozen for export. The cold storage facilities also handle salt-water fish. Both the U.S. and Japan are now investing in large Atlantic fisheries enterprises, to be based on processing facilities in Ireland.

THE NETHERLANDS

The Dutch have always depended on fish in the diet, as is evidenced by a steady increase in their catch. Aside from whaling, Dutch fishermen have usually confined their efforts to the North and Irish Seas.

The Dutch pioneered the cultivation of oysters. A few of the river estuaries have been adapted for controlled oyster farms, making Netherlands the second ranking oyster producer of Europe.

Herring and related species make up about two fifths of the total catch, this proportion having dropped during the fifties. Molluscs, mainly common mussels, come second as one fourth of the catch; flounder and related species make up almost one tenth and cods a slightly smaller portion.

Close to half is consumed unprocessed, slightly less than a third (29.0%) cured, 9.5% canned, and only 3.7% frozen. The remainder goes for reduction and miscellaneous purposes. As facilities expand, freezing is expected to grow.

Herring makes up the bulk of the catch, being salted on board, slightly over half of which is salted whole. Much salted herring is subsequently smoked by a special process to render golden smoked herring. Some fresh herring is hot smoked to make bloaters. Late in the season, much herring is pickled in vinegar and spices (marinades).

Smoking is also used for processing of mackerel, whiting, and sprats as well as fresh-water eels. Pickling is employed for mussels.

Only about 20,000 metric tons annually are packed in cans, four fifths being ocean fish and the rest mussels. A major portion of the catch is marketed unprocessed.

Belgium

Most fish are caught in nearby coastal waters. The catch is modest in size. Occasionally fishing boats venture into the Irish Sea, more frequently into the North Sea or English Channel. One half the landings is cod and related fishes, almost one fifth flounder, halibut, sole, etc., and one tenth shark and other elasmobranchs.

Three fourths of the catch is marketed unprocessed. Of the remainder, one tenth is frozen, 6.0% cured, 3% canned, and 3% goes for reduction. The domestic frozen fish industry has a production capacity of 200 metric tons per 24 hours and a cold storage capacity of about 1200 cu. m. Belgium has a unique practice of delivering raw unprocessed fish by parcel post.

Belgium is one of the few countries where stockfish is prepared, the fish being dried without salt. Drying with salt is nevertheless more common. The two best-known products are "zoute haring" and "labberdaan" or hard dried salted cod.

Smoking is far more popular than salting and/or drying. Belgium imports about 2000 metric tons of smoked fish every year. In addition to the smoked products some 12,000 tons of salted herring are imported, most of which is smoked. Depending on both the degree of salt cure and the method of smoking, no less than seven types of salted and smoked herring are prepared. Some of the smoked products are marinated, but unlike many countries most of the fish is cold pickled. Many additional fish species are smoked and/or salted, each to give its own special products. Lack of adequate refrigeration facilities hampers the sale of frozen fish.

Canning is very limited, with little prospect for future development. The reduction plants process several kinds of products: white-fish meal, herring meal, whole meal, condensed fish solubles, and oils of herring and cod liver.

FRANCE

Like most maritime nations of Europe, France has fished the rich fisheries in the Northwest Atlantic for centuries. In the Treaty of Paris in 1763, which ceded Canada to the British, St. Pierre and Miquelon were retained by the French to be used as bases for fishing. The French also retained the right to dry fish on the Newfoundland shore.

In addition, the waters of the Bay of Biscay are very rich in fish, and are the source of most of the sardines processed in France. While the Mediterranean fisheries are not nearly as productive as the Atlantic they materially add to the over-all picture. Fish cultivation is increasing along the south coast. Oysters and mussels are cultivated in Brittany.

Over 60% of the fish catch is consumed fresh. Since these figures include both fresh or chilled and frozen fish, it is impossible to tell the proportion actually frozen. This percentage has undoubtedly been increasing rapidly during the last few years. Like many countries, France has been changing to freezer trawlers.

Tuna fishing has greatly expanded all over the world since the last war. As elsewhere, most of the tuna is canned. Canned tuna in France is surpassed only by canned sardines. Tuna is preserved in three styles: chunks, flakes, or fillets, in oil, tomato sauce, or natural. Sardines are packed in oil, à la ravigote, in spices and garlic sauce, or in tomato sauce. Both herring and mackerel may be marinated in white wine. Over 16% of the (1961) catch was canned.

The rest of the food fish is cured. Of the 124,000 metric tons cured in 1961, 45% was salted cod and 10% salted herring. On the Mediterranean most of the anchovy is salted. A number of species are cold smoked.

Most of the drying in the north of the country is done with hot air, much of it in connection with cod. The salting is usually done on board ship before reaching port.

France is one of the few western countries where fish sauces like *nuoc-mam* and *nam-pla* are known. After the independence of Indo-China, many of the French residents returned to Europe and created a demand for these exotic sauces.

Since France still has colonies or former colonies all over the world, she is admirably suited for building fishing bases at strategic places. The French have enlarged the facilities at St. Pierre and Miquelon, but that is about all. Japan has stepped into this void and built bases, with French financial assistance, at Tahiti, New Caledonia, Ivory Coast, Dakar, etc.

WEST GERMANY

The Germans have fished for centuries in the North and Baltic Seas. But with the boundary revision at the close of World War II many of the Baltic ports were lost. Kiel is about the only fishing port left to West Germany on that sea. West German fishermen have moved farther out into the Northwest Atlantic until at present around two thirds of the catch is from the North Sea and the waters near Iceland. The Federal Republic has acquired within the last decade a growing trawler fleet and are presently able to process a growing portion of their catch at sea. As early as 1955, West Germany started high sea fishing in the Davis Strait off western Greenland.

One third of the catch belongs to the cod group. Mullet and related species comprise one fourth with almost as many herring. More than one third of the catch is consumed unprocessed, one fourth canned, one seventh cured, and only one twentieth frozen. Most of the sea-frozen fish are reprocessed on land before marketing.

One fifth of the landings goes to reduction into oil and meal, the latter being a comparatively new trend that started around 1950. Besides offal and inedible fish, the fish meal factories receive food fish whenever the supply exceeds the demand. Fish meal factories have become in recent years an integral part of the trawler fleets, since processing can be done at sea. Some salted cod is processed and landed at foreign ports.

Salted herring, as in most countries, is one of the oldest products prepared at sea. Since shrimp is so perishable it is usually boiled on board. The smaller shrimps, exoskeletons, and offal go for fish meal. Fish-liver oil is extracted on board.

Both hot and cold smoking are used for curing. The hot smoked products are bloaters, sprats, mackerel, and eel; cold smoking produces kippered herring and smoked salmon.

West Germany produces a number of marinades made chiefly from herring. Three items are peculiar to them (see Chapter 5, this volume). Depending on the kind of process employed, the product may be pickled herring, grilled herring, rollmops, Bismarck herring, etc.

A comparatively new way of curing is seen in oil preserves, consisting of salted or filleted fish in oil. The best-known products are saithe slices and small fillets and matjes herring; these products do not keep indefinitely.

Heat processing of fish has been steadily increasing since the end of World War II. Some of the products include cured items subsequently canned to prolong their keeping time.

ICELAND

Iceland was colonized by the Vikings about the ninth century A.D. Until about the middle of the last century, agriculture was the chief industry and fishing was of secondary importance. After that time, the climate became unsuitable for wheat growing and fishing gained in relative strength. Now fish products account for over 90% of the total value of exports. The waters around Iceland are extremely rich in marine life, and have been fished by many nations throughout the centuries.

Over 90% of the catch is about equally divided between cod and herring. The ground fish have in later years shown a declining trend. The disposition of the catch is presently as follows: two fifths frozen, one third cured, one fifth goes to reduction plants, and less than one tenth is marketed unprocessed. Before development of the freezing industry, most of the catch was cured; this percentage is likely to decline.

Almost three fourths of the herring catch is reduced to meal and oil. Salted herring is one fifth; the frozen proportion is approaching one tenth. The disposition of the cod landings is radically different. Close to two thirds is frozen, as fillets or in the round. One fifth is salted, one tenth dried unsalted to make stockfish, and only a few percent goes into fish meal. Minor quantities of cod and herring are landed at foreign ports.

The production of stockfish had fluctuated appreciably. In the eighteenth and first half of the nineteenth centuries stockfish was exported. Then, until a few years before World War II, the trade practically ceased. During the war it declined, but was subsequently resumed. Much of this production goes to tropical West Africa.

Like most fisheries, the most rapid increase has been in fish freezing. The first freezing plant was built in 1930, but the fish industry did not realize its potential for about five years. In 1945 no less than 68 plants produced about 600 tons of fillets per day. Fourteen years later the number of plants had grown to 80 with a capacity of 1400 tons. New freezing plants are starting.

Iceland in 1959 had about 40 fish meal factories and some newly built trawlers that process on board. Both cod-liver and herring oils are significant products, although synthetic vitamin A is reducing the volume of the cod-liver industry.

FAEROE ISLANDS

After World War II, especially after extension of the Icelandic fishing limits, the Faeroe deep sea fisheries more or less concentrated on west Greenland waters. Old trawlers were bought in Iceland and the U.K., new ones were built, and at times nearly 200 fishing vessels, trawlers, schooners, cutters, sloops, and dories were engaged in this ambitious fishing enterprise. One of the trawlers, the 955-ton "Saklaberg," is equipped with a number of processing lines. Several plants have been built ashore, and the Faeroese now process, salt, fillet, or freeze the principal part of the total catch of cod, the most important species caught.

Half the export consists of klipfish and salted fish, supplying Brazil and the Mediterranean. The U.K. buys most of the reported fresh-market fish. Frozen cod fillets are sold to the U.K. and U.S.

GREENLAND

Although Greenland is discussed under Denmark, it is felt that the future importance of the island may warrant additional comments. New fisheries have been developed in recent years in the Davis Strait and off the west coast of Greenland. A number of fish bases have been built along the west coast, Faeringhavn being the chief one. At this base nearly 100 boats a day may visit during the fishing season and 200 may be stationed there. Freezing-salting and filleting plants, power stations, wharves, and a salt silo have been built. In all, 62 salting plants, two filleting and freezing plants, and two shrimp factories are in operation along the coast. They also process fish oil.

The cod may be salted, dried unsalted, or filleted; the shrimp is canned or frozen. The shrimp and cod fillets are exported to the U.S.; the other two items go to southern Europe.

III. Baltic

FINLAND

It is natural to expect Finland with its long coastline and many lakes to have a fishing industry. Half the catch is herring, more than one fourth fresh-water fish, and the remainder unsorted. The last item emphasizes that much of the fishing is done by local small boats that do not sort the fish; most of their catches are sold directly to fish retailers that supply the consumer.

TABLE II
TOTAL CATCH OF BALTIC COUNTRIES
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
U.S.S.R.	1,523.0	1,485.0	2,245.3	2,051.0	3,250.0	3,616.5
Finland	44.0	46.1	63.6	66.0	67.1	64.7
Poland	12.5	47.1	117.7	183.9	185.5	179.6
East Germany	—	13.6[a]	64.6	114.4	130.1	—
Sweden	129.2	193.9	206.8	254.7	267.3	290.0

[a] 1947.

Two thirds of the catch is marketed unprocessed, one sixth frozen, one tenth cured. Only a little above 1% is canned and the rest, almost one fifth, goes for reduction. No major changes are expected in the immediate future, although the proportion of the catch frozen will most likely expand.

POLAND

At the end of World War I Poland once again became an independent nation. With the acquisition of a seacoast a marine fishery began to develop. The first major fishing port was Gdynia. Additional ports were built at Jastarnia and Wladystawowo. Before the last war Gdynia had a freezing plant and an ice and fish meal factory.

After World War II Poland recovered broader access to the sea. She now has three big ports, Gdynia, Gdansk, and Szczecin. A new site was chosen at Świnoujście (earlier Swinemünde) in the Odra Firth to function as the chief base for the North Sea fisheries. A fleet of new modern factory ships has been acquired for the northern Atlantic. The port of Wladystawowo serves the Baltic fishing. At present there are in the fishing ports seven refrigerated storehouses, seven ice factories, nine fish unloading centers, two fish meal factories, one cod-liver oil plant, and six cutter hoists.

The chief Polish fishing waters are, besides the numerous inland rivers and lakes, the Baltic with the important Gulf of Danzig and the major coastal lagoons, Frisches Haff and Stettin (Szczecin) Lagoon, and estuaries of the Vistula (Wista) and the Oder (Odd).

In 1961 over half the catch was of the herring type. Cod, hake, haddock, etc. account for over one fifth, mackerel almost one twelfth. One tenth of the catch was from fresh water, most of which was consumed fresh.

Before World War II most of the Baltic Sea catches were smoked. The two main species were sprats and flatfish. Even today the U.S.S.R., U.S., U.K., South Africa, West Germany, and the Philippines are the only countries that smoke more marine products than Poland. However, none of these countries even approaches Poland in the high percentage of the total catch that is smoked.

Two methods of preserving the fish until reaching port are used. Baltic fishermen usually pack the catch in ice, while the boats fishing in the North Sea salt the catch. Most of the herring caught in the North Sea is salted; the Baltic herring is processed into smoked, canned, or pickled products. The latter procedure accounts for only one fourth of the total herring catch.

Only about 40% of the cod is processed. Of this amount 15% of the total catch is smoked, 10% filleted, 10% salted as "Laberdan" (hard dry cure), and 5% canned in oil and tomatoes. Approximately 70% of the sprats is canned or smoked and the rest is made into fish meal. Mackerel is usually salted but at certain seasons, when it is plentiful, is brought to port fresh and used for canning or smoking.

Most of the other fish is consumed fresh or frozen for use by the canneries in their slack season. An increasing amount of the catch is undoubtedly being frozen and stored until needed by the consumer. This is especially true with the acquisition of high-sea freezer trawlers and the construction of refrigerated storages at the ports.

Poland is following the Soviet lead and building modern freezer trawlers with an operating range of 12,500 miles, thus enabling them to join the international fleets at the fishing banks of Newfoundland, Labrador, and Greenland, and off the African coast. The first trawler was delivered in 1959, to be followed by 54 additional ones in the next 15 years. The number includes all types. Land facilities are also being improved. Technical aid is rendered to African lands and others.

EAST GERMANY

Fishing in East Germany is still largely a private enterprise. Several cooperative institutions are coordinating their efforts. The state, however, is entering into both catching and processing. Rostock is converted into a sizable combine on the Soviet pattern with large refrigerated warehouses.

The freezing capacity of the country is being expanded, particularly at sea. High sea fishing is being provided, with freezing trawlers with a daily capacity of 200 metric tons—resembling the Soviet vessels. The first two such vessels are in service and nine more are on order. The production of frozen fish fillets will thereby increase from 3,000 metric tons in 1958 to 32,000 tons in 1965. These ships are built in East German shipyards, as are the herring trawlers also equipped for freezing, through which it is hoped to quadruple the present herring catch and make East Germany self-sufficient in this respect. Transport ships (two or more) were built in 1962 to service the fishing fleets in distant waters.

East German trawlers have joined the Soviet fleets fishing in the Davis Strait, off Newfoundland (Flemish Cap) and off Labrador. These East German fishing boats have experienced what Soviet units noted at an early stage: that the waters in Barents Sea, around Bear Island and off Spitsbergen, have shown a persistent decline in catches in latter years.

Carp is the major (60%) fresh-water fish, the remainder being eel and pike. As in most countries, the greater part of these fresh-water species is undoubtedly eaten fresh.

A marine-fish research institute for East Germany is operating in Rostock-Marienehe, devoted primarily to sea fisheries and fish utilization. It is also in charge of education as well as developing standards for various sectors of the fish industry. A special branch is located in Sassnitz and serves Baltic fisheries. Inland fisheries have their scientific center in Berlin-Friedrichshagen. A special carp institute is operating in Königswartha. The branch for catching techniques is in Gross-Glienicha, near Potsdam on the Sacrower Sea.

Sweden

Although close to some very good fishing waters, Sweden imports one third of its intake, largely in processed form; the exports are raw unprocessed fish sold to continental Europe, the U.K., and Denmark.

While most of the fish are caught in nearby waters, Swedish fishermen fish also in Icelandic waters. Close to two thirds of the total catch is herring and one fifth cod. Some of the whitefish is filleted and frozen. Most of the herring is salted. A considerable proportion of the latter goes into semipreserves: packs of old tradition, such as Scandinavian anchovies, herring tidbits, etc. (see further Chapter 6 of this volume). Half the catch is registered as used for miscellaneous purposes, being largely this very industry. One fourth is consumed unprocessed, one tenth goes for reduction, and another tenth in equal amounts to freezing and canning. Almost the same amount is cured.

Another specialty of Sweden as well as Norway is fishballs. They presumably constitute the first ready-made food ever to be canned, even prior to the soups of the U.S.

IV. Soviet Fisheries

Soviet Union

Among the major transitions taking place in the Soviet Union during the last decade, those concerning fish have an important place. Russia in earlier years depended for fish primarily on regional resources: internal seas, rivers, lakes, and other waters. In 1900 only one sixth of her fish consumption came from the oceans and it was eaten mainly in coastal areas. It is a major accomplishment to have doubled the total fish catch in less than fifteen years and this expansion has taken place at an accelerated rate since the middle 1950's.

An increase of more than 10% in the fish catch has been registered almost every year since 1953. This was accomplished by greater exploitation of the bordering oceans from which two thirds of the fish supply now comes. Ocean fishing has been given priority, and it is anticipated that more than 80% of the constantly growing catch will come from the sea by the end of 1965.

The achievements of the Soviet fishing industry are due primarily to the acquisition of a considerable number of large fishing vessels equipped with modern radio navigation and search equipment (in many cases special searching vessels) as well as with new mechanized equipment and more productive fishing gear. In 1951–1960 alone, the number of vessels increased 2.8 times, and their motor power 3.7 times. At present, vessels of at least 300 h.p. provide about four fifths of the entire fish catch.

Present Catch

The Soviet catch has increased by more than 2 million metric tons since 1938, when it amounted to something over 1.5 million tons. In 1962 it was more than 4.1 million tons, 400,000 tons above the figure for the previous year. Included in this amount is a catch of whales and other marine mammals, estimated at about 500,000 tons.

Soviet Aquatic Catch (exclusive of whales and other mammals)

1913: 1.05
1930: 1.28
1940: 1.40
1945: 1.13
1950: 1.76
1955: 2.50
1956: 2.85
1957: 2.53
1958: 2.62
1959: 2.75
1960: 3.05
1961: 3.25
1962: 3.62
1963: 4.12

In the first phase of the postwar maritime drive, major emphasis was placed on the Atlantic flank. In the present second phase, the Pacific flank is given priority.

Plans providing for a Soviet fishery catch of 4.6 million metric tons by 1965 were changed in July 1962 by a ministerial decree, raising this goal to 5 million metric tons with the high sea catch given as 3.6 million metric tons. The anticipated catch for 1964 is 4.50 million metric tons.

Stagnant Inland Catch

The U.S.S.R. shares with Western Europe, the U.S., and now also Japan the detrimental effects of industrialization on the productivity of inland waters. Extensive and damaging pollution is accompanied by the diversion of large amounts of water for irrigation and hydroelectric dams. The most spectacular of these consequences is the dwindling of the mighty Caspian, the northern part of which is seriously affected and will entirely disappear in a few decades.

Concentrated efforts have been made to compensate these losses through artificial local fish production from ponds, wherever climate permits. The many dams, covering 5 million hectares, are being exploited.

Background

An annual increment to the U.S.S.R. population of more than 3 million people, the vagaries of the climate making agricultural production less dependable, and dwindling catches from inland waters (p. 315) are the three driving forces in the Soviet upsurge in marine fisheries. To this can be added the desire to improve the nutritional standard.

The U.S.S.R. recognizes that the fishing industry is a vital part of the Soviet economy, and that fishery products provide the people with more than one third of their total consumption of animal protein. In recent years, even greater emphasis has been placed on increasing the fishery intake because livestock production has failed to reach predetermined goals.

Despite gains in catch volume there are certain signs of dissatisfaction, as part of the homeland catch includes growing amounts of less desirable and small-sized species, such as sprats, sardelles, khamsa (Caspian anchovy), etc., which have only a limited demand. The catch of esteemed fresh-water species, which have a basic demand (i.e., pike, sazan, carp, bream, sheatfish, etc.), has declined. This deficiency will presumably be met by the new marine tuna fisheries (see below).

Catch Pattern (Species)

The sources of the Soviet fish catch are presented in Table III. Herring is the principal catch in the eastern regions of the Soviet Union; 90% of all flatfish are caught in the Pacific region. The Atlantic-Arctic catch breaks down in the following way: 60% in the Barents Sea and 35% in the Baltic. The remainder, from inland waters, comes largely from the Black Sea and the Sea of Azov.

TABLE III
SOURCES OF SOVIET FISH CATCH
(average for 1958–60 in 1,000 metric tons)

	Atlantic-Arctic				
	I[a]	II[b]	III[c]	Pacific	Black and Caspian Seas
Flatfish	9.5	6	3.5	90	0.5
Cod and related gadoids	90	75	15	10	—
Herring, sardines, etc.	46	2	7	30	24

[a] I = total.
[b] II = Barents Sea and White Sea.
[c] III = the Baltic.

Cod dominates the Arctic catch (85%). Next comes the rapidly growing landing of ocean perch. Soviet planners anticipate a drop in the current availability of cod and an appreciable expansion in ocean perch.

Filleting machines and other equipment are adjusted to meet this switch. Sprat, together with the Baltic herring, cod, and flounder, account for a third of the Baltic catch.

Distant Fishing

The modernized fishing fleet has enabled the fishing industry to go into new distant fishing grounds in both the Atlantic and Pacific Oceans. Soviet fleets are catching fish along the shores of Alaska (Bristol Bay), Kodiak Island, off Yakutat, at British Columbia (Vancouver Island), and northern California. They operate further in the waters west of Greenland (Davis Strait) at the Grand Banks of Newfoundland (Flemish Cap, Sverdlovsk Bank) down to George's Bank and off Long Island. Smaller fishing fleets have been spotted off the coasts of North Carolina and Florida. Exploratory fishing has started in the South China Sea, in the Indian Ocean (around the Chagas Islands), and in the Red Sea.

Efforts are presently concentrated on raising the catch in equatorial waters of both major oceans. Special measures are being taken to boost the catch of bass, mackerel, pike, saury or saira, and bring in tuna from the southern Pacific, together with horse mackerel and mackerel from the Sea of Japan. The haul of shrimps, oysters, squids, sea kale, and other marine products is also expected to mount. The Pacific saury fishery is a new undertaking for which the immense Japanese expansion paved the way.

Since 1956 the experimental ship "Nora" has been exploring the tuna potentialities of the Pacific. A number of tuna vessels of new design are presently being built by the U.S.S.R. in its own shipyards as well as in Japan, Scandinavia, etc. The U.S.S.R. will join the big scramble for the migrating tuna shoals of the oceans and on a large scale.

The incorporation of large-tonnage power vessels into the fishing fleet has improved the economics of the industry by increasing the fish catch per fisherman. Some 78% of the catch originates with 7% of the vessels.

African Sardines

Russian freezer ships have fished sardines (*Sardinella aurita*) all along the west coast of tropical Africa, and *Sardinops* spp. further south in the waters of South Africa. These frozen sardines have been brought back to the homeland, to Archangelsk, to Cherzon on the Black Sea, or to Kaliningrad on the Baltic.

A growing number of vessels have taken part in this fishing ever since 1957. A specialized air-conditioned freezing trawler of the so-called "Tropik" class has been designed and put in operation to meet the particular needs of this fishery.

Due to the high temperature and humidity, efficient freezing facilities are essential prerequisites. The abundance of this sardine and the large catches secured in each trawl further require that the freezing capacity be large.

Several freezing trawlers have in seven trips per year each brought back 4,000 tons of sardines from this South Atlantic area.

Catching is done largely through light attraction combined with hose suction. Chilling is accomplished immediately by pumping the small fish into ice-cold ocean water tanks on board through a hose some 100 feet long. Slime formation detrimental to quality is suppressed in this way.

Processing at Sea

Most significant, however, is the build-up of the processing potential at sea. Some vessels combine catching and processing functions. Medium fishing trawlers operate at sea at sufficient capacity to serve effectively this new fishing fleet. Large trawlers with the necessary equipment for suitable processing are of increasing importance. On such vessels, fish is frozen (whole, cleaned, headed, or filleted), canned, or salted. Fish meal and oil are manufactured on board. All scrap is utilized. Fleets are serviced by special transport vessels with refrigerated holds which receive the finished products.

Major attention is devoted to the large-scale expansion of the Soviet processing potential at sea in Chapter 11 of Volume IV. (Various phases with respect to the utilization of these catches were analyzed in Chapters 7 and 19 of Volume II.)

A few pertinent facts will be briefly reviewed here. The Soviet development differs basically from that of Japan by placing almost complete emphasis on processing capacities of the floating fleet. This has the advantage of a minimum of political entanglements. Only one distant base appears to have been created, namely, that on Cuba (see below). Some transshipment takes place at Port-of-Spain, Trinidad.

Otherwise, the entire fleet is serviced from the homeland. Water and food may occasionally be picked up in English ports, at Vera Cruz in Mexico, or at Walvis Bay in Southwest Africa.

Freezing Trawlers

There are three types of so-called large freezing trawlers (BMRT), listed below in chronological order, almost identical in size, tonnage, and velocity but with improvements in disposition of space and in equipment (length 84.5–85.2 meters; velocity 12.5 knots):

(1) "Pushkin" type (Hochwaldtswerke, Kiel)—2,470 gross tons.

(2) "Mayakovsky" type (Nosenko shipyard, Leningrad)—3,170 gross tons.

(3) "Leskov" type (developed jointly with Poland)—2,890 gross tons. See further Volume IV, Chapter 11.

Motherships

A very advanced factory ship, the "Andrei Shakharov" (14,000 gross tons), was delivered in 1961 from East German shipyards at Rostock. The processing is highly automatized, in fact almost completely. A special device allows separation of large and small fish and mechanized chilling operations. The vessel is equipped with sardine dryers, automatic oil extractors, an ice-making plant with a capacity of 25 metric tons per day, and a carton-folding machine. This ship is presently operating in the Red Sea and the Indian Ocean.

The large Soviet factory ship "Vladivostok" (14 knots, 17,000 gross tons, 408-man crew), built to order in West Germany, is part of the Soviet Antarctic whaling fleet. It also serves as a mothership for fishing operations in the North Pacific and is basically a freezing plant. The holds for frozen fish have a capacity of 3,200 cu. m., those for finished fish meal of 4,400 cu. m., with additional tanks for oil of 1,100 cu. m.

A new crab-canning factory ship, the "Aleksander Obukhov" built in Leningrad, joined the North Pacific fleet in 1963. The canning line has a daily capacity of 200,000 cans. This is a greatly improved version of earlier such canning units. A new series of giant processing ships (43,000 tons), starting in 1964, is being launched from the Admiralty shipyard, Leningrad.

West European and Japanese shipyards are reported to have orders for 25 motherships and 2 whaling ships (13 are 8,000 gross tons each, the remainder 20,000 gross tons each) for delivery to the Soviet Union by 1965. No less than 66 factory ships are being built in Stralsund, East Germany, intended for fishing tuna, herring, horse mackerel, and sardine in tropical waters. Some of these are delivered and in operation in the tropical Atlantic. Each has a frozen fish capacity of 500 tons and is equipped to manufacture 60 metric tons of fish meal. Some 20 major freezing trawlers, factory ships, transport vessels, and tuna ships are being built in Japanese shipyards for delivery in 1964–65.

Transport Ships

The growing distance between fishing grounds and home bases is causing concern and initiating new developments. Even the modern freezing trawlers are harassed commercially by their lengthy unproductive travels to and from the fishing locations.

The modern transport vessels for frozen fish are classified as belonging to the "Aktubinsk" class. They maintain a temperature of —18° to —20°C. (0°F.) in the holds. These vessels are of 10,000-ton displacement and have ten cargo spaces (both holds and twin deck spaces) with an aggregate volume of 8,628 cu. m. Cooling is done by means of plain-surface single- and twin-row coils mounted on the walls and ceiling.

Average Catch

The average annual catch per large freezing trawler with stern holds (BMRT) was reported for 1962 as 5,500 metric tons each. The highest annual catch recorded in 1962 for a BMRT vessel was 8,000 metric tons. Soviet fishery experts hope to increase the regular take of BMRT types of craft to an average of 7,000–8,000 tons yearly by resorting to transfer and transport vessels, thus prolonging the fishing time of the BMRT. Special devices have been installed for such load transfer.

The average catch per medium fishing trawler (SRT) was about 1,400 metric tons in 1962. The highest recorded catch for this type of vessel was 3,200 tons in 1961 (*Pravda*, January 28, 1963).

Bases

The U.S.S.R. is belatedly following the Japanese patterns and creating transoceanic bases for its operational fleets. The largest is being built at Ateras Cove close to Havana. A 10-year agreement regulates the operation of the base, which is to be run by Cubans and also used by their growing oceanic trawler fleet. This is planned as an unloading port for 110 Soviet trawlers taking part in the Middle Atlantic fishing. A second refueling and transshipment base is Port of Spain, Trinidad, mainly for the fleet fishing in the Caribbean and off the coast of Mexico. Food and water are regularly picked up at Vera Cruz, Mexico.

A second major base for Soviet fishing is to be built at Alexandria in Egypt, supplemented by a smaller base in the Red Sea at Ras Banas.

Curing

Salted dried fish is produced in relatively small quantities, and usually very small fish such as the smelt are used. They are prepared by preliminary salting or a combination of salting and drying. In the first method, the fish is salted to a 3–4% salt content and dried at 120–150°C. down to a moisture content of 28–30%. In the second method, it is sprinkled with salt and put into a very hot oven (250–300°C.); the resulting salted, cooked, and dried product has a specific taste and aroma and a crumbly consistency.

Drying

Dried unsalted fish is much in demand. It is prepared from species such as sea and Caspian roach, bream, pike-perch, chehon (*Pelecus cultratus*, related to carp), halibut, turbot, shemaya (*Chalcalburnus chalcoides*, related to freshwater bream), and vimba. The fish is first salted slightly to a 3–6% concentration, then rinsed, and slowly dehydrated in a hanging position in air for a minimum period of 15 days (in spring or autumn). More recently special dryers have been used in which dehydration is carried out in air at 30°C. and 70% relative humidity, but a tastier product is obtained with the first method.

Dried fish has an old tradition in Russia. Dorsal flesh parts of the sturgeon ("balyk"), carp, and roach are commonly available dried. Pike, smelt, pike-perch, and others appear as salt-dried products. Such dried fish is used for making fish soups or is consumed directly as a snack. In some cases dried vegetables are pressed with fish into briquets.

Vacuum drying has been applied rather commonly in newer plants. A special plant for freeze-drying was opened in 1954 at Rostov-on-Don. Fish fillets (cod and others) and fish stuffing used for fish sausages are important items. Such freeze-dried material is used in the manufacture of ready-made dishes.

Salting

Salting occupies second place in Soviet fish utilization. Bulk freezing is often preferred for space reasons even when the fish later is submitted to salting in the final processing on land. Nevertheless there are several floating salting factories in full operation. A high degree of mechanization has been accomplished. One essential feature is the introduction of vibrators for dense packing of the barrels. Such measures reduced crews in floating salting factories to half.

Low-temperature salting is generally practiced to reduce losses of fat and protein as well as to control microbial activities. In most cases temperatures of 0°C. (32°F.) or below are maintained. Even in the southern regions, as the Caspian and the Black Seas, these rules are followed by ample use of ice.

Salting is accelerated by mechanical circulation of frequently renewed brine. In ocean fisheries salting in barrels is becoming increasingly important. Two new methods are being used experimentally to accelerate maturing. A special enzyme preparation is added to the brine. Salted fish are tightly packed in crates or airtight boxes without brine. Enzymes within the fish are adequate to ensure the maturing of such salted fish. In packing salted fish without brine in these sealed containers, loss of nitrogenous substances through microbial activity is averted.

Factory ships with refrigerated holds have been salting Atlantic and Arctic herring with the addition of sugar, which supports a lactic acid fermentation. This is done immediately after catching, and the fish after preparing are cut into pieces, placed in tin cans holding 3–5 g. fish, sealed, and stored in holds at about 0°C.

A new type of herring-processing vessel, the "Lamut" built in Japan, has been in service in the Atlantic since 1959. This 4,982-ton vessel is equipped for automatic processing (salting and freezing) up to 120 tons of herring a day. Top speed is 14.5 knots. A second type called "Nikolai Isaienko" (4,500 tons) has been delivered by a Tokyo shipyard. An improved SRT-trawler of the "Atlantik" class has been specially designed for the North Atlantic. Its capacity is 200 metric tons, speed 12 knots, with a 600-h.p. motor. The salting facilities are mechanized and automatic and the holds maintain —15°C.

Highly mechanized salting factories are serving as motherships in the North Atlantic.

Smoking

Smoked fish enjoys immense popularity and is made from frozen, salted, or fresh stock. Cold and hot smoking are practiced, and production is said to approach 100,000 metric tons. Smoked fish is commonly available in the food stores. Smoking of fish (e.g., cod, gray mullet, salmon, and sprat) for packing in oil depends entirely on the cool climate and would be hazardous under warm conditions. The continuous smoking line at the Moscow combine has a 24-hour capacity of 40 tons. Regional methods with varying types of smoking kiln still prevail, as in the Far East, the Caspian, and the Baltic. But efforts to mechanize, automatize, and control the smoking process in detail are numerous. There are new-type smoking kilns.

Certain smoke-dried products constitute a special group called *balyk*—almost a condiment. This is prepared from the dorsal flesh of highly rated species such as sturgeon, sevruga, beluga, King salmon, sockeye salmon, Siberian salmon, char, nelma, and muksun.

Along with conventional methods of producing smoked fish, electrical smoking using steam or smoking fluid is employed. All stages (drying, baking, and smoking) are carried out with electrical energy, steam and smoking fluid being the smoking agents. Even small fish are processed by this method. For hot-smoke products, most species of fresh-water fish and certain ocean fish are used, e.g., Baltic herring (salake), Caspian sprat, cod, sea perch, catfish, ruff, plaice, mackerel, pelamids, gray mullet, and saury (saira).

Attempts to supplant traditional smoking methods with dips have been numerous, particularly since the Soviet public health authorities confirmed the presence of certain cancerogenic substances in the smoke. These have to be removed to below a certain minimum benzpyrene value.

Canning

The canning industry produces some 240 types of canned fish pack in some 200 plants. Several of these have been erected since 1953. They are located chiefly in the large landing ports, but also close to flourishing inland fisheries.

Frozen fish frequently constitutes the basis for continuous, seasonally undisturbed operations of the canning plants. This is true of the herring from the Baltic and the Atlantic, sardines from Equatorial Africa, and several others. Special studies have been devoted to sardine canning, utilizing five classes of raw material (Baltic herring, Caspian sprat, sprat, Caspian anchovy, and small North Sea herring), and to manufacturing six types of product (sardines in oil, in tomato sauce, with tomato, au naturel, with vegetables, and in small pieces).

The U.S.S.R. enjoys a great variety of canned fish products: au naturel, with tomato sauce, and in oil—previously fried or not. Stews are made and packed from several species of salmon (ragout). Besides the traditional packs of herring, sprat, sardines, salmon, tuna, mackerel, etc., other canned species of fish include cod, bream, grayling, plaice, sole, pike, sturgeon, several whitefish, smoked lamprey, etc. The canning of saury is a new endeavor in which the Japanese have led the way (see p. 360). Large new factories for this pack have been built on the former Japanese Kuril island of Shikotan.

Specific Russian fish varieties used for canning are the "muskun" (*Coregonus muskun*), "som" (sheatfish), "syrok" (*Coregonus peled*), "nelma" (*Stenodus leucichthys*). Several are packed in jelly, such as nelma, Baltic herring, muskun, eel, lamprey, perch, and whitefish. Liver of cod and salmon is canned both au naturel and in tomato sauce, and is increasing in importance as a basic food, since cheaper synthetic methods have been adopted for the manufacture of vitamin A. Roe of cod and plaice is also canned; products include fish soups of the puree type. Fried fish (cod, plaice, Baltic herring) is frequently canned in tomato sauce.

Canned fish with various vegetable garnishes is being distributed on an increasing scale. It is manufactured mostly in the southern regions such as the Volga-Caspian and Azov-Black Sea basins where there are vegetable surpluses. Preparations from fish and molluscs with the inclusion of seaweed (sea kale, etc.) are being produced on the Pacific coast.

Miscellaneous

Sturgeon milt is canned with vegetables or in tomato sauce. Baltic herring (50–55%) is marinated with vegetables (onions, carrots, etc.), and a number of jellied canned fish are packed (e.g., sprat, perch, etc.). Several combined fish (30–35%) and vegetable (70–75%) products (as sturgeon with beans) are available.

Barges

Processing barges towed up and down rivers and along the coast were introduced by the Russians on the Volga at the beginning of the nineteenth century. Later canning barges for salmon and crab were towed along the rivers of the Sea of Okhotsk, Kamchatka, Sakhalin, and Eastern Siberia.

The crab-cannery barges of the Far East are being augmented by large crab factory ships, capable of also processing fish.

Fish Combines

The word "combine" is employed to signify processing plants uniting into a single entity almost every phase of utilization through processing. At least two large-scale fish combines were built in the late twenties and early thirties, in Murmansk and in Astrakhan. They have been constantly modernized, rebuilt and expanded. Several postwar combines have been constructed, some huge with thousands of workers.

The fish combines in large cities have in addition lines operating on a 24-hour basis for making ready-made dishes, such as fried fish and cooked fish in different sauces (parsley, dill, etc.), most of which is packed in plastic bags. Dry ice is used for distribution in trucks, canteens, and retail stores.

MURMANSK CENTER

The Murmansk Fish Combine has grown from a small operation in the 1930's to handle about 700,000 metric tons, or one fifth of the 1960 Soviet marine catch. From this the Combine produced 300,000 tons of frozen, salted, and smoked fish, plus 15 million units of canned fish. The canning operation is substantially mechanized; filleting, weighing, and other work are still done by hand. Further mechanization is planned.

The Murmansk unit comprises a refrigeration warehouse with an ice-making unit, several canning plants with a can-making factory, two salting units, a smoking plant (present capacity 23 tons per 24 hours), a fish meal factory, and a plant for medicinal oils. One canning plant produced 25 tons of finished products per 24 hours. The whole array of processed fish products is manufactured here with the exception of ready-made fish (fried or broiled). For such items there are several processing lines in the Fish Combine of Moscow together with a defrosting establishment.

The Murmansk combine covers an area of 100 acres and employs 4,000 of which 1,500 are designated as laborers. Some 300–400 trawlers operate in season out of Murmansk. Approximately one fifth of the whale brought in is processed on board. In this respect the combine also is a kind of central kitchen.

The 1965 goal is 340,000–350,000 tons of fishery products (excluding canned fish). The trend is toward relying more on factory trawlers for supplies of fresh and frozen fish. The Combine sells its products to a state marketing organization (RYSBYT) for distribution locally and to various parts of the U.S.S.R.

ASTRAKHAN

One of the biggest industries in Astrakhan is an enormous fish-processing plant—so-called combine—employing upwards of 5,500 people. Here every kind of fish processing is carried on, including canning, can making and tin recovery, freezing, smoking, salting, reduction of waste products, and preparation of the Volga brand of caviar. It operates several refrigerated barges for collecting caviar and live fish.

The Astrakhan combine, named for Mikoyan, has for a long time been the pride and the pioneer of Soviet fish processing. It is claimed to have started large-scale freezing of fillets in 1935 in a highly modern plant with a capacity of 50 tons per 24 hours, applying methods and equipment developed by the Refrigeration Research Institute (VNIKhI) in the period 1931–34.

The combine is located in the delta of the Volga, a few miles from Astrakhan, and serves the entire Volga-Caspian area. It handles annually 75,000 tons of fish, 80% of all fish from the Volga-Caspian area. It manufactures 12% of all canned fish in the Soviet Union, 80% of sturgeon caviar, and 70% of all cured sturgeon fillets (balyk).

ODESSA

Odessa on the Black Sea obtained a new canning and freezing plant in connection with the construction of a new port complex. The port can now accommodate ocean-going trawlers and even the large Soviet whaling vessels.

RIGA

A new fishing port primarily designed to handle Soviet catches of Atlantic herring is under construction at Riga in the Latvian Soviet Republic. It is situated at the mouth of the Daugava River.

The basin has been deepened to receive motherships such as "Riga," "Konda," and "Kaliningrad" and large refrigeration fishing ships with a displacement up to 4,000 tons.

Well underway toward completion is a 10,000-ton capacity cold storage plant with rooms for temperatures of 0° to —2°C. and enough space for 4,000 tons of frozen fish at —18°C. The second most important feature is a herring-processing plant with canning, salting, and smoking facilities. In many trawlers, herring is subjected only to primary salting in barrels. Twelve conveyor lines will transport the herring barrels to the plant. Here the herring will be washed, checked for quality, put into barrels again, salted, sealed, and stored. Hand labor is used only for filling barrels; electric vibrators will be employed for a denser fill of the barrels. The capacity of the processing plant is about 100,000 tons of herring a year. A freezing store with two chambers is provided against the contingency of factory overload. The chambers will hold 4,700 tons of herring. Conveyor belts will connect them with the processing plant.

The port includes two miles of dock frontage, warehouses, processing facilities, and housing for 15,000 people.

PETROPAVLOVSK

A large cold store equipped for freezing of fish takes care of most fish brought by trawlers to Petropavlovsk on the east coast of Kamchatka, and for transient storage of fish frozen at sea or elsewhere. The actual capacity of this cold store is reported as follows: storage capacity for frozen fish, 8,000 tons; freezing capacity, 250 tons fish/day; manufacturing capacity for block ice, 120 tons/day. The storage space holds a temperature of —20°C. The ports of Nakhodka and Vladivostok on the coast of the Sea of Okhotsk have been modernized and expanded to meet the needs of the anticipated growth of Pacific fisheries.

MISCELLANEOUS

Several combines are operating in the peninsula of Kamchatka, and on the island of Sakhalin. Large modern units have been constructed in Kaliningrad (earlier Königsberg) in the Baltic, and in Archangelsk, facing the White Sea.

Whaling

Soviet participation in Antarctic whaling expanded greatly in the fifties—from 112,000 tons in 1950 to 214,000 tons in 1957. The whaling fleet was recently enlarged with two large modern units, "Sovyetskaya Ukraina" from the Nikolayevsk shipyards and "Sovyetskaya Rossiya" (slightly larger, 45,000 tons), described as the most modern whaling factories in the Antarctic fleet today. The refrigerator holds have a capacity of 2,000 tons, and the tanks are capable of holding 18,000 tons of blubber. These ships can freeze some 100 tons of whale meat and liver daily, and store 1,800 tons of frozen products. They have a displacement of 44,000 tons, and are reported to be the largest vessels in the Soviet merchant fleet. They are equipped with modernized processing lines and scientific laboratories.

Their cruising range is given as 9,000 miles and their speed 16 knots. Accommodation on board is for 500 men with mess rooms, library, cinema, and recreation rooms. A helicopter is carried for spotting whales.

The build-up in whaling seems to be enormous. In 1960 a third large new whaling factory appeared in the news. This unit is reportedly built in an East German shipyard and named the "Yuri Dolgoruky." It is to lead the Soviet whaling flotilla in the Antarctic. This fleet's home station is Kaliningrad.

Two smaller whale-oil refineries, about 18,000 gross tons, have been built at Kiel (Western Germany) for work in Pacific waters. The cargo oil tanks have a capacity of about 13,700 cu. ft., refrigerated cargo holds about 4,000 cu. ft., and fish meal holds about 5,600 cu. ft. These floating plants will produce all the traditional items: whale oil, whale meal, refrigerated whale meat, vitamin oil, and whale-liver pulp. A unique feature is that outside the whaling season they are designed to be used as fish factory ships for producing frozen fish fillets, fish meal, fish-liver and vitamin oils. The processing plant is located on the flensing deck.

A Soviet whaling fleet, besides these modern factory ships, includes about 30 whale-catching boats, a scientific research vessel, and support ships.

V. Mediterranean

The Mediterranean is becoming a fished-out sea. At the same time the pressure on its limited resources has been intensified by the evolution of new nations around the shores, such as Libya, Tunisia, and lately Algeria, who are catching their own fish, with newly established fleets. This leaves Italian fishermen—and others in the same area—with the choice between a dwindling livelihood and going farther afield.

EGYPT (UNITED ARAB REPUBLIC)

Fish has always played a key role in the Egyptian diet. It is probable that fish as food was more or less seasonal before the building of the regulating dams.

According to 1961 figures, three fifths of the fish landed was from fresh water. The balance was listed as unsorted, indicating that the landings were sold by local fishermen to fish mongers or direct to the consumer. In the absence of utilization figures we may assume that most of the catch is consumed unprocessed.

Modern Egypt is suffering from overpopulation. The government is turning to the sea as a possible source of food. It is conducting surveys of all territorial waters to ascertain their productivity. Even the new high Aswan Dam will not alleviate the situation appreciably.

TABLE IV
CATCH OF MEDITERRANEAN COUNTRIES
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Egypt	38.1	42.8	57.4	88.5	92.0	118.0
Libya	2.0	2.2	2.5	2.2	2.3	2.4
Tunisia	9.6	12.2	12.0	16.3[a]	—	—
Algeria	21.1	30.0	23.5	25.6	—	—
Morocco	43.7	68.6	112.2	154.1	164.9	162.9
Italy	181.2	156.6	218.0	213.3	239.6	218.6
Yugoslavia	16.8	21.2	23.8	30.9	37.3	30.3
Greece	25.0	33.6	52.8	95.0	—	—
Turkey	76.0	—	111.1	89.4	82.3	—
Israel	1.7	2.5	9.2	13.8	14.9	16.4

[a] 1958.

Japan has been exporting canned saury and other canned goods to Egypt. But in order to bolster their own trade balance the Egyptians are building a tuna- and sardine-canning plant and three shrimp-freezing plants to process these items for export. A cannery at Damietta will process sardines, "musa," anchovies, crabs, and shrimp.

LIBYA

Most Libyans are Arabs and traditionally no fishermen; most of this country's fish are therefore caught by Italian, Greek, and Maltese nationals. The fish found in the coastal waters may be larger than is common elsewhere in the Mediterranean, chiefly due to the fact that these grounds are not overfished. The city of Tripoli has six canneries for sardines and tuna, caught mainly along this section of the coast.

TUNISIA

Just how long the fisheries off modern Tunisia have been exploited will probably never be known. Ancient Carthage was situated here. Undoubtedly, the Carthaginians used fish since the time of their ancestors; the Phoenicians were seafarers.

The present Tunisian landings consist of almost one half (44.7%)

unsorted fish, almost as many (44.1%) sardines, one twelfth tuna, and 1.3% each of crustaceans and sponges.

Practically all of the unsorted fish are consumed unprocessed. The sardine industry is concentrated to the ports of Mahdia, Monastir, and Sousse, the locations for major canneries.

In their migrations the tuna follow close to the Tunisian coast when passing through the Sicilian Strait from May 15 to July 1. This is an important fishery since ancient times (see further Chapter 4, Volume IV).

ALGERIA

Before independence in 1962, Algeria's catch was included in the figures for France. After seven years of civil war it would be unjust to try to analyze Algeria's fishery trends at this early date.

MOROCCO

The fisheries off the northwest coast of Africa have been known for centuries. Portugal and Spain were probably among the first regular visitors to these waters. The fishing was largely coastal while Morocco was still a colony of France and of Spain. After independence, fishing was given greater emphasis.

Sardines are the mainstay of the business. Three fourths of the catch is sardines, tuna one tenth. The utilization pattern is radically different from most African countries in that less than one tenth is consumed unprocessed. The major portion (2/3) goes for reduction, one fifth is canned, one tenth is frozen, and insignificant quantities are cured.

The most conspicuous factor in recent developments is the rapid expansion of fish meal manufacture from sardines. Fish flour of high quality, standing storage in cardboard containers for 2 years, is also manufactured. It has been used experimentally in biscuits, soups, stews, etc. A plant with 700-ton capacity has been built for making this product.

The manufacture of Moroccan canned sardines is limited by the high price of cans; this is said to be probably the chief cause for the 60% drop in sardine production from 1957 to 1960. Agadir, Safi, Tangier, and Casablanca are the centers of the sardine-processing industry.

Tuna and mackerel are next to sardine in volume, and are packed in olive oil for export. The can price is less critical for these kinds of fish.

A thriving shrimp industry has recently been growing up around Tangier. While some shrimp is used locally most is frozen for export. The frozen fish are used locally mainly for home consumption or canning. Bulk-frozen sardines are sold regularly to the French sardine-canning industry.

ITALY

One would expect Italy, with its long coastline, to look to the sea for one of its major food supplies. Fish has been a dietary staple since the days of ancient Rome. Italian fishermen have stayed near their coast and not ventured far from the Mediterranean. Consequently most of their fish is consumed unprocessed. In 1961 over 85.7% of the catch was marketed this way. Of the remainder, 7.2% was cured, 3.8% canned, and 3.2% frozen. The consumption of anchovies and sardines in brine has been steadily declining in the last decade.

The canning industry, on the other hand, has been expanding. Tuna is the largest single item canned. The canneries in recent years have been importing frozen tuna from other countries. Japan is the chief supplier. In fact within the last few years Japanese-Italian companies have been formed to build modern processing plants and refrigerated facilities on Italian soil. Japanese deep sea fishing fleets will supply most of the raw material.

Tuna is the chief product and is canned in oil, au naturel, or as tonetti (small tuna in oil). The latter is an Italian tuna specialty famous throughout the world.

Sardines and anchovies are canned as well and are still preserved in brine. Sardines and other non-tuna fish in oil are decreasing. Another world-famous Italian product is canned eel. Eels are raised in lagoons on the Adriatic coast of north Italy.

Some 125–150,000 tons of fish are acquired abroad each year, almost 40% of the total intake. The Blue Plan (Plano Azurro), for considerable expansion of fishing, aims at self-sufficiency and is given high priority. Italy is being driven to take such measures by hard necessity.

YUGOSLAVIA

Yugoslavia has conducted coastal fishing for centuries. Until recently, when the Japanese built a 500-ton tuna vessel on Yugoslav order, practically all aquatic foods were caught in lakes or nearby waters. This new tuna ship is based at Casablanca and fishes in the North Atlantic.

In 1961, more than two fifths of the catch was sardines or other members of the herring group, one third fresh-water species, and less than one tenth mullets and related species. Most of the sardines is canned for export. Like other nations without highly industrialized fisheries, most fish, aside from sardines, is consumed unprocessed.

GREECE

The coastline of Greece and her many islands indicate that the Greeks must have depended on fish in the diet for centuries. Fish was probably a vital food in the Golden Age of Pericles.

Of the 1959 catch one third was classified as unsorted, indicating that much of the fishing is done by small local boats selling their catch direct to fish dealers. Sardines and their relatives comprised a fourth, mullets and the like about one sixth, and fresh-water species one eighth. Trout cultivation has been successfully introduced.

The statistics for 1958 show that 62.8% of the catch was consumed unprocessed, 13% cured, 5% frozen, and 1.2% canned. The percentage of fish frozen has undoubtedly increased since then.

Salting of sardines is probably the most common curing practice in Greece, a holdover from an age-old practice of the rural people.

The fishing firms in late years have been acquiring more freezing trawlers and are working in the Atlantic off Northwest Africa. Most of this catch is tuna. Planning is underway for construction of a Greek fish meal factory.

Japanese fishing interests have been collaborating with the Greeks in the expansion of their fisheries.

TURKEY

Turkey is believed to have considerable fishery resources in the Mediterranean Sea, the Black Sea, and the Sea of Marmara. The potentialities of these waters have not been assessed. Turkey has, however, very recently extended its territorial fishing limits from 3 to 12 miles. In addition to the marine fisheries, composed mainly of tuna, bonito, mackerel, and dolphin, there are the carp, eel, and yellow-pike fisheries of the inland waters.

Shrimp is a small portion of the total catch. Iskenderun near the Syrian border is the center of the shrimp industry for southern Turkey. The main shrimping grounds are in the Gulf of Iskenderun and off the coast of Mersin-Karatas-Yumurtaluk. Estimated total annual shrimp landings for Iskenderun are 40–60 metric tons.

Over 70% of the total catch is marketed unprocessed, the rest is cured (24%) or otherwise processed. Tuna and bonito are exported to the canneries in Italy and Yugoslavia. Mackerel and dolphin are reduced in a state-owned factory in Trabzon. Shrimp is sold fresh or exported to Syria and the Lebanon. Some is frozen (the facilities are not mentioned).

The Turkish Meat and Fish Office, a government agency, is reportedly planning the development of marine fisheries in cooperation with a private fishery firm on the Island of Marmara in the Sea of Marmara. Special advice has been sought in Japan and a special study delegation from that country visited Turkey for first-hand observations and formulation of a long-range program.

ISRAEL

Israel entered the field of distant-water fishing with a Norway-built trawler in 1961. Her success resulted in the building of a second freezer trawler. Following a cruise to the Grand Banks off Newfoundland early in 1963, she began fishing off the northwest coast of Africa.

Israel also conducts deep sea fishing in the Canary Islands fishing grounds in the Atlantic, in the Indian Ocean off the Malagasy Republic and the coast of Africa and the Red Sea. Eilat, Haifa, Caesaria, Tel-Aviv, Acre are the important fishing ports and markets provided with cold storage facilities. The majority of the high sea catch is tuna and sardine. These endeavors are pursued jointly with Japanese and Norwegian interests through special companies. The Sea of Galilee still is a source of fish.

Coastal fisheries in the Mediterranean yield few edible fish. A substantial part of the domestic fish supply consists of carp and tilapia produced in fresh-water ponds.

Israel at present produces about 60% of its fish supply. With a per capita consumption of over 28 pounds of fish per year, fish is generally marketed unprocessed. In 1962, 15 million cans of fish, mostly sardines, were packed. The imports consist of frozen cod and haddock, salted herring from Scandinavia, and sea bass from South Africa. Some canned sardines are exported to Rumania and South Africa.

VI. Black Sea and Caspian Fisheries

IRAN

Iran's catch comes from three sources: the rivers, the Caspian Sea, and the Persian Gulf–Indian Ocean coasts. The most important fish caught in the Caspian Sea is the sturgeon; others are white salmon, whitefish, bream, pike, catfish, and herring. Species caught in the Persian Gulf include sardine, tuna, bream, snapper, mackerel, and shrimp. The industry is centered around Hormuz Island. The Elburz Mountain rivers and streams flowing north and south supply small river trout and other edible fish.

TABLE V
BLACK SEA AND CASPIAN FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Iran	—	25.0	25.0	—	—	—
Bulgaria	5.6	6.4	7.2	7.9	—	—
Romania	30.0	—	33.0[a]	42	46.5	51[b]

[a] 1958.

[b] Soviet Statistics.

The king of the Caspian Sea is the sturgeon, 25–2,500 lb. in weight. Although its flesh is somewhat oily, it is a tasteful and delicate fish and one of the most expensive on the local market. The sturgeon fisheries lie between Astara in the northwest and Bandar Shah to the east, a distance of 600 miles. Sturgeon, like salmon, run up rivers to spawn and enter the warm creeks around Bandar Pahlavi and Bandar Shah. They are netted in their migrations by 45 fishing stations in four administrative sectors for the extraction of caviar.

After the caviar is extracted, the fish are shipped to Hassan Kiadeh for cold storage. Over 2,000 tons of sturgeon are caught annually and 98% of it is exported. FAO has recently proposed to the Iranian Government to set up plants to can surplus sturgeon.

Caviar

Iran is a major source of the world caviar supply. Four species of sturgeon abound in the waters of the Caspian Sea and provide the roe for 96% of the yearly world production of over 2,000 tons. Russia produces 90% of this caviar and Iran 5–6%. Iran's caviar production during the fiscal year 1957–58 was 163 metric tons as compared with 127 tons the previous year. It exports caviar mostly to the U.S.S.R. and also to France, the U.S., and West Germany.

The roe of sturgeon is collected in a basin, gently rubbed through a coarse sieve, washed, and mixed with salt. Each kilogram of roe is mixed with 44 g. salt. The salted roe is packed in cans, kept in ice and sawdust, and shipped at temperatures just below freezing.

The most commonly used preservative for caviar is boric acid, which is acceptable in all countries except France and the U.S. Salting is employed for caviar exported to these countries. It cannot be frozen nor can it be sterilized by heat.

First-grade caviar is golden in color with grains large and firm. The second grade is dark gray to black with grains small and loose. The product is known under the name of the variety of sturgeon from which it originates, such as beluga, sestruga, and assetrine.

Fish from the Persian Gulf is frozen, smoked, salted, or canned, and shrimp frozen or dried, but these products are small in quantity.

The most important fisheries enterprise in Iran is the Iranian Fisheries Company, a government agency. The exploitation of fishery resources in the Gulf began in 1955 with the organization of a joint venture between Iran and Japan. This arrangement was subsequently terminated. The shrimp fishery in the Gulf was substantially developed by a joint Iranian-U.S. Company, starting operation in 1958.

Bulgaria

Lack of adequate refrigeration and transportation has always been a factor in the scarcity of fish and other seafoods in Bulgaria. The government has recently initiated a number of fishermen cooperatives designed to tap the vast resources of the Black Sea. The chief port is Sozopol near the important port city and provincial capital of Burgas.

One of the chief species caught is the dolphin, a marine mammal averaging 50 lb. in weight. One ship during the season can catch up to 2,000 on a voyage of 3 or 4 days. The dolphins are skinned, deboned, and salted aboard ship. Due to lack of storage facilities the freshest steaks are stacked on deck. They are kept up to 2 days without salting. On docking about one half is distributed to the markets fresh or salted. It is probable that some of this is dried for the use of local cooperative farms. The other half of the catch is taken to the Sozopol cannery where it is processed. Canned dolphin resembles canned tuna.

Other species of commercial importance are tuna, bonito, mackerel, gray mullet, and turbot.

Bulgaria is now, with Soviet help, developing a high sea fleet for fishing around Iceland, Newfoundland, and off the coast of tropical West Africa. Present plans are eyeing fishing also in the Indian Ocean.

Romania

Information about Romanian fisheries is practically unavailable to western scientists. A Japanese shipbuilding company has, however, delivered two multipurpose stern-fishing vessels (3,603 tons) for initiating fishing in the waters of the northwest Atlantic. Until now fish cultivation and fresh-water fish, mainly from the Danube, have provided most fish on the market. In 1960, 78% of the catch originated in this river.

VII. Northwest Atlantic

United States

The United States ranks fifth at present in the amount of fish landed each year, but as late as 1956 it was second in rank. There are many major fishing grounds close to the coast. The continental shelves are

Table VI
Northwest Atlantic Total Catch
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
U.S.	2,260.1	2,416.6	2,748.6	2,814.5	2,931.9	2,904.9
Canada	836.8	1,052.9	972.2	934.5	1,019.6	1,115.1

comparatively wide along the East, Gulf, and Alaskan coasts, which is usually conducive to high fishery production.

In 1961, two fifths of the catch was of the herring group (mainly menhaden), one fifth molluscs, one twelfth of the mullet group (ocean perch, jack mackerel, sheephead, etc.), and 6.9% crustaceans. A meager 2% of the total catch was from fresh water, yet this amounted to 56,200 metric tons, which puts the U.S. seventh in the production of fresh-water species. Much of the catch is consumed unprocessed, but some of the whitefish, pike, and perch is filleted and frozen. An interesting sidelight is the utilization of carp. In some of the mountain states the reservoirs and lakes are seined for this species, which is frozen whole and ground up for trout and other game fish as feed.

Utilization is as follows: a little more than one third of the total catch goes for reduction, a little below one third is marketed fresh, one fifth canned, and one tenth frozen. Only 1% of the catch is cured.

Almost the entire menhaden catch from the East and Gulf coasts is processed into oil and meal. In fact, four fifths of the U.S. production of fish meal is from this species. Practically all of this meal is used for broiler growing. There was a 20% increase in fish meal production in the fifties.

Canning in the U.S. started in 1819 when Underwood heat-processed lobsters and salmon in Maine. Since that time the canning industry has become big business. The largest cannery in the world was recently built in Puerto Rico. Most of its output is canned tuna. Much of the raw material is caught by foreign fishermen and transshiped to Puerto Rico. About half the raw tuna has been imported in the last few years. In 1950 almost all tuna was canned in oil, but a decade later a complete switch took place with nearly the entire pack in brine.

The production of canned sardines declined considerably in the fifties. The Maine sardine pack remained fairly constant, but the Pacific pack was in 1960 only 12% of that for 1950, due to the disappearance of the Pacific sardine. The salmon pack has also declined but not so drastically. The total pack during the fifties declined about one third, caused chiefly by smaller catches. Other species processed by heat include mackerel (both Pacific and jack), alewives, and crab. In addition a considerable number of fish preparations, such as oyster stews and clam- and fish-chowder, are heat-processed.

Frozen fish products have shown a marked increase, fillets and fish sticks being the leading items manufactured. Approximately half the raw material is imported. Shrimp freezing has shown a similar growth but here also imports account for more than half the pack.

CANADA

Many of the most productive fisheries in the world are near Canada—the Grand Banks, George's Bank, and the Davis Strait, west of Greenland. On the west coast the offshore waters near the "inside passage" are the source of many fish, but the tuna boats hunt in the East Central Pacific off Baja California. In addition many fish are caught in the Great Lakes, Lake Winnipeg, Great Slave Lake, and the myriad of other lakes found in eastern and northern Canada.

Almost two fifths of the catch belongs to the cod group (mainly Atlantic cod) and three tenths is herring. The salmon group accounts for about 8% and the flounder and related fish for 7.5%. One fourth of the catch is frozen, one fourth cured, one fifth marketed fresh, and close to one fifth taken to reduction plants.

By far the largest proportion of the frozen fish consists of fillets for domestic and U.S. consumption. Cod, haddock, halibut, hake, and freshwater fish make up the vast bulk of production. Some of the fillets are reprocessed into fish sticks. Others are breaded and precooked. In the 6 years prior to 1959 the production of fillets on the Atlantic Coast almost doubled.

Many of the fish are cured along the Atlantic in almost the same way as when Canada was first settled. Most of the cod is dry-salted, sun-dried, or pickled. Artificial dryers are now in use in many areas. Along the Gaspé peninsula a special cure is produced, the Gaspé cure, known throughout the world. Some areas still smoke herring to produce "bloaters" or related items.

Canadian sardines are mainly small herring caught in weirs along the Bay of Fundy. That area has the largest sardine cannery in the British Commonwealth. Canned salmon is the chief product of the west coast canneries. All five species of Pacific salmon are utilized. Tuna is also canned. As the Canadian boats cannot supply the demand, additional material is imported.

Experimental work has been done on using filleting trimmings for the production of fish flour. A new process which dehydrates a fish and potato mixture, forming readily reconstituted flakes, shows considerable promise. Other new products are "fishfurters," fish loaves, fish croquettes, and whitefish sausages.

VIII. Caribbean and Gulf of Mexico

MEXICO

The largest portion of the landings is crustaceans. These account for almost one third of the total, practically all shrimp. Molluscs comprise one seventh, sardines one ninth, and fresh-water fish one tenth. Aside from shrimp and other invertebrates, the majority of which are exported, most of the fish is probably used for local consumption.

TABLE VII
TOTAL CATCH OF CARIBBEAN COUNTRIES AND MEXICO
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Mexico	17.1	68.4	88.1	197.9	225.4	218.6
Cuba	10.0	8.3	11.5	31.2	31.1	35.9
Haiti	1.5	1.6	—	—	—	—
Dominican Republic	0.3	0.5	0.7	1.3	1.6	—
Puerto Rico	1.4	2.3	2.5	3.1	3.3	3.5
Bahamas	—	—	1.4	1.6	1.5	1.6
Jamaica	4.5	—	—	8.5	11.5	—
Guadeloupe	0.4	0.9	1.8	3.2	3.3	1.6
Martinique	2.5	2.5	2.8	3.3	3.1	—
Netherlands Antilles	0.1	0.1	0.6	0.6[a]	—	—
Venezuela	21.7	92.3	61.6	84.7	83.0	—

[a] 1957.

Mexico has made great strides in recent years in the canning and freezing industries, due largely to the great volume represented by the shrimp-freezing segment of the industry. There are 49 freezing plants in operation with a total capacity of 500 tons, which freeze principally shrimp. Canneries in operation in the country total 35. There are eight major reduction plants for production of fish meal.

The Banco Nacional de Fomento Cooperativo financed a new fishery harbor, the first to be specifically constructed with facilities to integrate all fishery processing operations. Work began in November 1962 by opening and deepening through dredging the channel and bays at the port of Alvarado, Veracruz. The main objective of the project is to increase production of market fish for the country's needs, and it will receive the catch of several hundred canoes and boats that operate in the area. Handling facilities will be for 80 tons daily, and a boat yard will handle boats up to 200 tons.

The center will also put into operation five 110-gross ton fishing vessels, geared for trawling, seining, and long-line fishing. The first of these have been delivered. They are being built in the Netherlands and are intended for instructing fishermen of the Alvarado Region. They can be used for shrimp fishing as well as for purse seining and beam trawling. They are Diesel-driven. The refrigerated holds have a capacity of 100 metric tons at 1°C. (33.8°F.).

A large new commercial fishing industry centered particularly on fillets, lobster tails, turtle meat, and other products, is coming into being along the Gulf and Caribbean coasts of Mexico in an area stretching to British Honduras. These new industries are doing much to stimulate economic activity in areas among the least developed in Mexico.

A recent improvement program increased freezing capacity at the shrimp-freezing plant from 6,000 to 12,000 lb. daily and procured new equipment. Deveiners are commonly used throughout in this important process.

Freezer boats carry the finished product to Miami, Tampa, and Port Isabel, Texas. A fleet of 25 boats serves the Mariscos del Golfo plant—the Bay of Campeche is noted for its high quality production, and shrimp and fish come from this area.

Shrimp is put up block-frozen in 5-lb. boxes, and individually quick-frozen in polyethylene bags weighing 3, 2.5, 1.5, 1 lb., and 12 oz.

Another shrimp-freezing plant is located at Merida, Yucatan, with a capacity of 9,000 lb. daily.

West Indies

The West Indies constitute some of the most densely populated areas in the New World. The Bahamas with 9 people per square kilometer and the British Virgin Islands with 14 are at one end of the scale, while Barbados with 538 is at the other. Only three other areas, Cuba with 61, the Dominican Republic with 64, and Dominica with 77, have less than 100 people per square kilometer.

All but five of the areas are governed by other countries. The Dutch-ruled islands have a common government, but many of the other islands publish their own statistics. The landings and their composition are given in Table VIII. Most of the unsorted fish is consumed unprocessed. Most areas do not supply their own needs.

Puerto Rico has one of the largest tuna-processing plants in the world at Mayagüez. There are two other canneries in that city and one at Ponce. The four plants can process 445–485 tons per day and store 8,600 tons of frozen fish. Much of the raw material is caught by foreign fishermen who deliver the frozen tuna to transshipment ports. Many of these have been built and enlarged with Japanese help. The bases at Willemstad, Curaçao; Port of Spain, Trinidad; and Philipsburg, Sint Maarten (St. Martin) are mainly for supplying the Puerto Rican canneries.

In the Dominican Republic cold storage facilities are fairly common throughout the country, facilitating the use of unprocessed and frozen foods. In Cuba an ambitious undertaking is being pushed to build refrigeration plants throughout the island. This is part of an over-all program to enlarge the Cuban fishing fleet with more boats and port facilities. Some of the vessels will be freezing trawlers for high sea fishing. The U.S.S.R. is giving technical assistance and building five of these trawlers; Japan has started delivering the large trawlers ordered from them. A new large fishing base at Ateras Cove is, through a 10-year agreement, to serve the Middle Atlantic fishing fleet of the U.S.S.R. (110 trawlers). (See p. 320, this volume.)

TABLE VIII
WEST INDIES FISH CATCH
(1000 metric tons)

Country	Year	Total Catch	Country	Year	Total Catch
Antigua	1962	0.8	Montserrat	1961	0.1
Bahamas	1962	1.6	Netherlands Antilles	1957	0.6
Barbados	1962	4.7			
Cuba	1962	35.9	Puerto Rico	1962	3.5
Dominica	1959	0.5	St. Kitts	1960	0.8
Dominican Republic	1961	1.6	St. Lucia	1960	0.4
Granada	1962	0.9	St. Vincent	1962	0.4
Guadeloupe	1961	3.3	Trinidad and Tobago	1962	7.5
Haiti	1949	2.1			
Jamaica	1961	11.5	Virgin Islands	1956	0.2
Martinique	1961	3.1	(U.S.)	1961	0.8

A U.S. firm recently agreed to develop a fish industry and frog breeding facilities in Haiti.

VENEZUELA

The catch is composed of over one third sardines, almost as many of the ocean perch group, one tenth fresh-water fish with slightly less tuna and half as many molluscs.

Almost all the fish is used for food; only 2.5% goes to reduction plants. A little over one third of the total is marketed fresh, slightly more canned, and one fifth cured.

Next to the U.S. canneries at Puerto Rico, it seems probable that Venezuela has the only sizable fish-processing industry of the Caribbean, comprising a canning center at Cumana and curing and freezing industries around Isla de Margarita and the Gulf of Cariaco.

Sardine canning is the major fish-processing industry (in 1962, 800,000 cases with 100 cans per case of 3¾ oz. per can). Since the industry was operating at only half capacity, the production could readily be increased to 1.5–2 million cases per year.

The Japanese tuna fleet fishing in the Atlantic Ocean has been encouraged to use Venezuela as a base and sell part of their catch to the canneries at Cumana, since they are not operating at full capacity and the sardine catch is not sufficient.

IX. Middle Atlantic

Spain

There are rich coastal fishing grounds around Spain. Sardines are found along all coasts, but are most abundant along the northwest shoreline and fairly plentiful in the Strait of Gibraltar. The related sprat is found here, and crustaceans, mackerel, horse mackerel, anchovies, and molluscs abound in these waters. Aside from the pouting, the water around the Iberian Peninsula is too warm for the gadoid fishes, yet bacalao (salted cod) is one of the staples of the Spanish diet. For centuries the Spaniards have been catching cod in the fisheries off Newfoundland and Greenland. It is green salted on the ships and finished in land-based plants along the Basque coast. Haddock, hake, and pollock are all caught in the North Atlantic and tuna and related fish farther south. Almost one third of the catch is cod, over a fourth the herring group, one sixth ocean perch and related fish, and over one eighth sold unsorted.

TABLE IX
TOTAL CATCH OF MIDDLE ATLANTIC COUNTRIES
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Spain	423.5	547.2	690.3	898.0	1,014.5	1,006.0
Portugal	247.2	292.1	429.5	475.1	500.7	518.2
Morocco	43.7	68.6	112.2	154.1	164.9	162.9
Mauritania	—	—	—	0.6	0.7	0.6
Senegal	—	—	—	122.1	126.9	133.4
Guinea	—	—	16.0[a]	—	—	—
Sierra Leone	—	3.0	0.5	17.4	18.8	21.0
Liberia	—	—	0.5	2.2	1.2	—

[a] 1956.

As one might expect, much of the food fish (two thirds) caught by Spain is consumed unprocessed. The remainder is processed, one fifth cured, and some 13% canned. Only a few percent of the catch goes to the reduction plants.

Nine tenths of the cod is salted and dried, accounting for almost one third of all cured fish. Anchovies in brine make up one fourth; conger eel, sea bass, and perch comprise the bulk of the remaining cured products, and are mainly dried and salted.

The main canned products are about equally divided between sardine and tuna, both in oil. In the last few years over 500 fish-processing plants have been operating in Spain; over 60% are for processing in oil, the rest for pickling.

Until the second decade of the latter half of this century practically none of Spain's fish was frozen. In 1962 a start was made toward construction of refrigeration facilities at both Cadiz and Santander, and a modest effort was made toward developing a trade in frozen fish. This interest has been stimulated by the recent construction of freezing trawlers operating off the African coast almost down to South Africa. Modern floating salting factories have been built, expanding Spanish participation in the Grand Banks cod fisheries. New modernly equipped salting and drying plants have been erected in the homeland.

PORTUGAL

Who discovered the Grand Banks fishing grounds off Newfoundland may never be known. However, it is fairly well established that the Portuguese fishermen knew about them a long time before the discovery of America by Columbus. Undoubtedly the explorations by Henry the Navigator's group discovered other fishing grounds.

Since the Portuguese fisheries are so old and many of the areas so far from home, it follows that a way to prevent the fish from spoiling on the way home had to be found. Consequently, curing by salting was used. Salt fish has become so integral a part of the Portuguese diet that even today 56.8% of their food fish is cured. Only 5.7% is consumed raw (fresh or frozen). The rest is canned. The actual percentage of salted fish is much higher in the native diet because most of the canned fish is exported. Most of the cod is green salted.

In 1962, 75,219 metric tons (4.1 million cases) of canned fish were exported. Of this amount over 78% was sardines in oil or sauce, more than one fourth going to West Germany, a little less than one fifth to Great Britain and Italy each, and slightly less to the U.S.

Besides having sizable fleets still operating on an annual basis on the Grand Banks of Newfoundland, Portugal started some years ago to send trawling fleets to northwest African waters. Due to increased competition and alleged depletion of resources, these trawlers have been compelled to move to more distant fishing grounds, off Southwest Africa and South Africa. The catches here are frozen on shore and picked up by refrigerated transport vessels.

Negotiations are in progress with the Japanese for building a fish base in Portugal and developing the Azores into a major Atlantic base.

For fish processing in the Portuguese province of Angola, see below (pp. 347-348).

MAURITANIA

The waters off Mauritania have been fished for centuries by many nations. It has been estimated that 80,000–100,000 metric tons of fish have been taken from them each year. Since there is no accurate estimation of the catch which was classified as unsorted, it is doubtful that these statistics include the fish taken from the Senegal River on the south boundary. Most of the fresh-water fish are caught by natives living along the rivers and consumed unprocessed.

The commercial fisheries are concentrated around the northern seaport of Port Etienne. There are three drying plants, processing 5,500–6,000 tons of dried fish every year, and two canning factories, one processing only lobsters which are locally abundant and the other canning tuna, sardines, shad, and herring.

The government plans to increase the processing potential to 40,000 metric tons. Spain is giving technical assistance.

SENEGAL

The Senegalese have been fishermen for centuries, but their boats are mainly log canoes (pirogues), which prevents them from going far from shore. They have not sorted the catch, indicating that most of it is consumed unprocessed.

Fish canneries at Dakar have an annual capacity of 30,000 metric tons of product weight, but these plants operate at only about one third capacity. Their chief supplier is the French and the Spanish also sell to them. Since they pack the natural or "salmon-style" tuna, not very popular in the U.S., some nations (e.g., Japan) use Dakar as a transshipment base for supplying the U.S., mainly Puerto Rican, canneries. The government is attempting to get these local canneries to process sardines in order to increase their output. It is also trying to build up a national tuna fleet. Frozen tuna is sent to the former mother country, France.

A pilot plant for the production of fish flour from sardines and tuna for supplementing baby food is operating at Dakar. The Norwegians are negotiating to build a sardine fish-meal factory at Dakar.

GUINEA

Statistics for this former French West African colony are unavailable. However, the fish production has been estimated at 6,000 metric tons, one third of which is landed by a joint Guinean-Polish trawling enterprise.

Most of the fish is marketed fresh. Negotiations have been held with Japan for the development of Guinea fisheries, to include more fishing vessels, a fish meal factory, and other base facilities. Yugoslavia is presently surveying Guinean waters.

SIERRA LEONE

Almost half of Sierra Leone's catch consists of sardines. Close to one fourth is listed as unsorted, one seventh is identified as ocean perch, and one eleventh as hake or related fish. Most of the fish is consumed unprocessed. A new cold storage facility has been built at Freetown where tuna and other fish are frozen and stored for transshipment to Puerto Rico and Europe for processing.

LIBERIA

Liberia is the oldest republic in Africa, but is still rather underdeveloped as far as fisheries are concerned. Most of the fish and shellfish are from the sea. They are usually consumed unprocessed in and around Monrovia, the capital and chief port. The main species are soles, crawfish, crabs, lobsters, and shrimps. There are freezing facilities at Monrovia and the Japanese have constructed a storage warehouse for 2,000 tons of frozen fish, largely for the transshipment of tuna.

X. Internal Africa

The landlocked central portion of Africa procures a great deal of fish from lakes and rivers. It is not possible to analyze each country separately. A few pertinent notes:

Lake Chad covering about 10,000 square miles provides a great deal of fish but primarily to the bordering countries. The Chad Republic catches more than 100,000 metric tons. There are several other lakes in this general region.

Some of the fish are consumed unprocessed. Most of them are dried (unsalted), but some salted or smoked fish are exported to adjacent regions.

Important river fisheries are those of the Niger and Senegal rivers. In flood periods fish migrate widely to return fattened when waters recede.

Further south, Ruanda Urundi has previously been the center of extensive efforts to expand fish cultivation on the basis of *Tilapia*.

XI. Southeast Atlantic

IVORY COAST

This former French colony has access to the rich Gulf of Guinea fisheries. Most of the fishing is done by coastal vessels.

A private U.S. firm concluded an agreement with French investors to construct a tuna-freezing and storage plant at Abidjan. The plant can freeze 130 tons per day, store 1,300 tons, and make 60–80 tons of ice per day.

TABLE X

SOUTHEAST ATLANTIC FISH CATCH

(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Ivory Coast	—	—	—	44.0	41.5	43.0
Ghana	—	20.0	20.0	31.8	34.5	42.4
Togo	3.0	3.1	3.3	—	—	4.3
Dahomey	—	—	—	28.0	28.0	30.0
Nigeria	—	—	42.0	58.5	48.5	—
Congo (Leopoldville)[a]	0.9	17.5	78.4	153.4[b]	—	—
Angola	26.2	113.2	254.0	252.0	241.5	269.3
Southwest Africa	4.0	9.8	256.5	289.6	353.0	407.0
South Africa	62.7	176.1	366.5	578.0	657.3	655.0

[a] No figures are available for Congo (Brazzaville).

[b] 1959.

An Italian-Japanese firm is constructing a tuna base. France buys substantial quantities of the tuna; the tuna fishermen are largely Basques who moved down here long ago and have developed a French market.

Most of the domestic consumption is unprocessed fish.

GHANA

Since independence, the government has been trying to improve the nutritional status of the average Ghanaian. As in many underdeveloped countries, the protein-deficiency disease kwashiorkor is a major problem. The officials plan to combat it by building up their fishing fleet. They have stern trawlers, side trawlers, freezing trawlers, and carrier ships either built or on order with a capacity of 150,000 metric tons or close to a trebling of present catches. In addition, irrigation dams are being built on the lower Volta River system, 213 altogether. These are being stocked with fish. The recent effective control of the tse-tse fly permits the exploitation of these resources.

With such an ambitious program naturally provisions would have to be made to care for fish in times of oversupply as well as for transporting fish into the interior. The latter problem is being solved by a fleet of refrigerated and open trucks.

A U.S. firm has refrigeration and processing facilities for tuna at Tema, near Accra. Their products are exported.

The government is building a cannery for sardines, salmon, and other fish as well as refrigerated storages, also at Tema. A smoking plant was built to aid in prolonging the shelf-life of fish for domestic consumption.

Japan, Norway, the U.K., U.S., and U.S.S.R. are all giving technical assistance to Ghana. China is largely active in the field of the freshwater resources.

In December 1963 an agreement was signed with U.S.S.R. for the long-range buildup of the marine fisheries of Ghana. A permanent joint commission was created for research and development.

Togo

Slightly over one third of Togo's landings are from the rivers of Oti, Mono, and Kara; several hundred basins as well as the brackish Lake Togo are stocked by the government. Most of the catches are consumed locally, unprocessed. Smoking, salting, and drying are commonly practiced but with primitive methods.

Dahomey

Only one fifth of Dahomey's fish landings are from the sea; the remainder come from fresh water. Although the Niger forms only part of the northern boundary it is the source of most of the fish, since this river is abundant in fish. The coastal lagoon, Lake Aheme, also furnishes part of the catch.

Nigeria

Like many of the new nations, the Nigerians have tried to improve the nutritional status of their people. One of their chief problems is the protein-deficiency disease, kwashiorkor. Therefore special attention is being given to the development of their fisheries.

Slightly over half the catch is from fresh water, one half of this from Lake Chad. Of the marine landings, over 87% is caught by canoe fishermen along the coast. Most of the marine fish is eaten fresh as is most of the non-Lake Chad fish. Most of the Lake Chad catch is smoked and dried, but is usually infested with insects, mainly dermestid beetles. These infestations can cut the protein content as much as 40%. Salting has been introduced in recent years in order to control the beetles. The dried smoked fish is usually sold in the southern cities. The bongal (*Ethmalosa* spp.) which is abundant in the Niger delta region is also smoked in quantities.

The Gulf of Guinea is being fished for tuna by at least four nations. The Japanese have been negotiating for a base at Lagos. The Nigerian government has plans for a terminal island complex of facilities for unloading, freezing, storage, reduction, and canning, which could also be used as a transshipment base. Poland is rendering technical advice in the development of their fisheries. A joint Nigerian-Polish company is operating out from Lagos with modern Polish stern trawlers of the "Dalmor" class.

CAMEROUN

This former French colony has only a limited coastline (186 miles). However, it is cut by numerous salt water lagoons which experts believe will become excellent fisheries.

It is too early to ascertain the potential of these sea fisheries. In 1960 only 6.1% of the total catch of 49,000 metric tons was from the sea. The bulk of the landings came from fresh water. Like most underdeveloped areas, the vast majority of the catch is consumed fresh. It is probable that until the catch exceeds the demand for fresh fish there will be little need for processing. However, if the sea fishing expands as expected, facilities for processing will undoubtedly be erected.

CONGO (BRAZZAVILLE)

The government of this former French colony has not released figures for their fisheries. This may be due to the fact that the majority of the catch is caught by natives in small boats who land their fish at many places along the coast and rivers.

A pilchard and tuna cannery has been operating in Pointe-Noire for some time. In 1961, it processed 450,000–500,000 cans per month. By autumn of that year the output had nearly doubled the 1960 monthly average of 375,000 cans. Most of the products are marketed within the Equatorial Customs Union.

A U.S. firm has been negotiating with the Congolese government for the erection of an additional fish-processing plant and refrigeration facilities at Pointe-Noire.

CONGO (LEOPOLDVILLE)

Lake Tanganyika, like Lake Baikal, is geologically very old. Almost 75% of the fish species found in Lake Tanganyika and its tributaries are endemic. The lakes of Central Africa and the Congo River system are the source of almost all fish landed. Pond cultivation of tilapia has been encouraged on a large scale.

Before the recent independence the Belgian officials, appalled by the high incidence of kwashiorkor among the natives, had built wharves, a 20 tons per day ice plant and cold stores, workshops, and offices capable of handling 550 tons per month a few miles south of Matadi on the Congo estuary. Not much is known of what has become of these facilities in the last few years.

Probably the country's largest fishery is in Lake Tanganyika, which stretches for about 400 miles along the eastern frontier. About two thirds of this catch consists of two species of clupeids, similar to sardines and treated in the same way.

Disposition figures for the fish caught are not available.

Angola

The Benguela Current coming from the Antarctic contains a rich marine fauna. The natives have fished these waters for centuries, and European participation dates from 1571. Fish processing in this area dates from the middle of the last century. Since much of the adjacent land is arid, the climate is ideal for drying of fish, still an important source of animal protein for natives in the interior. Until the development of the fish meal industry much fish was wasted. Before the introduction of the modern industrial method, sun-dried fish were ground into meal of low protein content. The meal is sold largely in Italy and Eastern Europe and directly to the Far East, chiefly Hong Kong and Singapore.

Horse mackerel and related fish constitute three fifths and pilchards and other oily fish one fourth of the catch.

For the last few seasons a Japanese fish meal factory ship, that spends the regular season in the eastern Bering Sea, has been anchoring off the Angolan coast and buying fish from the natives. This has created international friction since the Angolan factories need the fish. There are some 9 large and 36 small fish meal factories operating along the coast. There are two major plants in Luanda and a third under construction at Port Alexander (Porto Alexandre) in the south. Fish oil is burned in some places to heat the fish meal dryers. Total oil production is 2000 metric tons.

The Japanese are also buying frozen dressed redfish for their own markets. The viscera, head, and fillet trimmings go to Angolan reduction plants.

The fish-canning industry is centered at Moçâmedes (Mossâmedes) at Baía Farta, and is confined to tuna and mackerel. Around 1,500 tons of canned tuna are produced annually, but the demand cannot be supplied.

The pilchard catch from Tiger Bay (Baía des Tigres) bordering Southwest Africa goes for the manufacture of fish meal.

The fishing grounds off Angola were surveyed in some detail during 1963 with the cooperation of Japanese experts. On the outcome of these investigations hinges the prospect of future continued Japanese engagement in Angolan fisheries.

The coastal area has an abundance of lobsters, crabs, and shrimps, particularly off Luanda.

In Baía Farta there is a coastal fisheries records station. A central fish institute was started by the government in 1960. This agency controls all fisheries activities and has subdivided the country into three major regions (North, Central, and South).

Southwest Africa

The Benguela Current which flows north just west of southern Africa makes the Southwest African fisheries very productive. Walvis Bay is the major center for these fisheries. It is one of the most important fish bases of the world and was founded as a base for U.K. whaling ships. With the decline of whaling, its importance was reduced.

Around 1948 the main activity here was seasonal snoek fishing and catching of rock lobster which were taken to the Lüderitz cannery and freezer. Since 1949 the Walvis Bay pilchard landings have increased over 43 times. There are now six canneries there with a total quota of 600,000 tons of fresh fish to be processed. The maximum quota for the next 25 years has been set at 720,000 tons. Two new canneries will be built by 1965. About one third of the present population of 15,000 depends on the fish industry, either directly or indirectly. It takes 55,000 tons of fresh tomatoes to supply the puree for those canned in tomato sauce.

Since this former German colony was mandated to South Africa after World War I, its economy is often incorporated both statistically and administratively.

South Africa

South Africa is one of the major fishing nations of the world. About three fifths of the landings is pilchards or South African sardines. Cape hake and other cod-like fish make up one seventh, tuna one tenth, and maasbanker (horse mackerel) and related species one twelfth. Crustaceans, mainly rock lobsters, account for only 1.3%.

Almost half the catch is reduced to meal or oil, one fifth eaten fresh, one sixth cured, one ninth canned, 6.1% frozen, and 0.2% for miscellaneous purposes.

Perhaps the most widely known South African marine product is rock lobster tails. Most are frozen and shipped to the U.S. The offal of the lobster is processed into meal. Live lobsters have recently been shipped to France by air.

The best of the surplus Cape hake is filleted and smoked to produce Cape cod fillets for the export trade. Some is quick-frozen and sawed into fish sticks which are marketed unbreaded, unbattered, and uncooked. A comparatively recent development is the salting and drying of this species. One dehydrating plant has a capacity of 70 tons per day. About half the produce is unsalted. The hake livers are used to process liver oil. The offal and excess quantities (unsalable) go to the fish meal factories.

The pilchard catch is the backbone of the industry, and forms the foundation of the fish meal industry. A new plant at Gansbaai on the south coast is capable of handling 20 tons of fish per hour. It has two reduction lines, one of 15 tons and one of 5 tons. This plant is building its own fishing fleet.

Canning is an important way of preserving South African catches. In fact, South and Southwest Africa together are surpassed only by Japan and Portugal in volume of canned fish products exported. The pilchard catch is the basis of much of the canning industry. From 1944 to 1962 the output of canned pilchards increased over 74 times. One plant at Hout Bay produces 54 different fish products. Maasbanker and mackerel are also canned, totaling about one fifth of the pilchard pack. Snoek (the South African tuna) is not canned to a great extent; most are used fresh, but those landed north of Saldanha Bay are usually salted.

The fisheries of South Africa produce considerable amounts of oils, such as the hake-liver oil mentioned, and many body oils as well. Pilchard oil is one of the leaders. One ton of raw meal produces 10–16 gallons of oil. Most of the maasbanker oil is hydrogenated or otherwise processed for human use; pilchard oil is usually used for industrial purposes.

Unlike the U.S. and Peru that use mainly fatty fish for meal, South Africa uses nonfatty fish. A great potential for food to the undernourished colored population would therefore be the conversion of such meal into fish flour (fish protein concentrate) for human use.

XII. Southwest Atlantic

The Guianas

The Guianas (British, French, and Dutch Guiana or Surinam) on the northeast coast of South America are the only colonial holdings on the continent. Most of the catches are unsorted fish, around three quarters of the total; the remainder are chiefly shrimp. Surinam takes one tenth

Table XI
Southwest Atlantic Fish Catch
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Argentina	55.3	71.2	78.1	100.9	93.7	94.4
Brazil	103.3	144.8	174.3	257.1	281.7	—
Uruguay	3.6	3.5	4.1	8.0	8.8	5.9

of its catch from freshwater resources. Most of the fish is consumed fresh; the shrimp from all three countries is quick-frozen and largely exported. Shrimp is caught the year around off the coast of Surinam.

Japan is helping British Guiana to develop her fisheries. U.S. firms have built shrimp packing plants at Cayenne and St. Laurent, French Guiana.

Brazil

Croakers, mullets, and the like make up one third of the total catch, fresh-water fish one fifth, sardines, anchovies, and menhaden one sixth, shrimps and other crustaceans one ninth, and one tenth is sold unsorted.

The Amazon River system probably has the greatest unexploited fishery of any fresh-water source in the world. Unfortunately, the underdevelopment of the region is not conducive to a rapid expansion of this resource. Manaus is 1,000 miles from Belem. The pirarucu (*Arapaima gigas*) found only in the Amazon is the largest fresh-water fish in the world, frequently weighing 200 lb. or more. It is filleted on the river bank, lightly salted (about 10% salt), and dried for the use of rubber workers and other inhabitants of the region. The fierce piranha makes a tasty meal. Over 1,800 species of fish have been collected in this area. Other sources of nonmarine fish are the São Francisco and Parana Rivers and Lake Mirrim. Two land-based whaling stations are operating in southern Brazil.

Most of the sea fisheries are located on the continental shelf which extends along Brazil's long coastline. The most extensive shrimp fisheries are along the Santa Catarina and Rio Grande do Sul coasts, especially in Lagoa dos Patos. The industry is centered around Isla de Santa Catarina. Shrimp is frozen for export at Belem and São Luiz in the north. Blast freezers have been installed at Recife for the processing of lobster tails.

The canning industry is concentrated on the southern coast from Rio de Janeiro to the Uruguayan border. Sardines form the bulk of the pack.

Besides the pirarucu, sea fish also are salted. In Rio Grande do Sul the chief species are croakers, drums, weak-fish, and catfish. Farther north flying fish are salted and sold in the interior. Sand smelt (manjuba) has been canned experimentally in the state of São Paulo.

The fish meal industry is comparatively minor. In 1960 there were only 16 small plants operating mainly around Rio de Janeiro (at Niteroi) and in Rio Grande do Sul. Most of the raw material used for fish meal is offal and other scraps from processing plants. Occasionally whole fish may be used to raise the protein content of the final product.

The Japanese have been helping the Brazilians to develop their fisheries. The introduction of modern methods caused some resentment among the native fishermen with their jangadas. The differences were finally settled when the Japanese agreed to train Brazilian fishermen and transferred some of their ships to Brazilian registry.

URUGUAY

Of the total catch two thirds is hake, pollock, and forkbeard, one sixth of the mullet group, one seventh unsorted, and 2.1% elasmobranchs. More were undoubtedly caught since no fresh-water fish are listed and Argentina catches over 14,000 tons largely from the River Plata, the boundary river between these two countries.

In the absence of statistics it is assumed that most of the fish is consumed unprocessed.

ARGENTINA

Argentina's fish and shellfish landings have shown a steady increase over the last two or three decades. The total catch is composed of two fifths hake and related fish, over one seventh sabalo (*Prochilodus platensis*) and other fresh-water fish, one eighth tuna, one ninth anchovies, one tenth of the ocean perch group, and 7.2% molluscs. In 1960, over half the catch was consumed fresh, almost two fifths canned, 5.0% went for reduction, 4.8% frozen, and 0.8% cured.

The fish are caught mostly on the continental shelf which extends out about 200 miles along the Argentina coast. The Rio de Plata, actually an estuary extending up the Uruguay and Parana Rivers, varies from fresh to salt water. The majority of the fresh-water species come from this region. The cold Falkland Current brings nutrients from the Antarctic which favor the hakes and anchovies and other species not important as food fish, but nevertheless forming significant links in the food chain.

Fish such as skate, tuna, and horse mackerel are considered trash fish in Argentina.

The canning industry was originally based on sardines and anchovies but now bonito and mackerel are also processed. The center of this industry is Mar del Plata which has about 80 canneries. This city is also the center of the comparatively new frozen fish industry; the frozen fish are shipped via refrigerated trucks to Buenos Aires. Mar del Plata also has a fish meal and oil-processing plant. A new reduction plant is being built at Puerto Deseado in the south. In 1960 there were 16 reduction plants in the country. Ten of these processed freshwater fish.

The large red-shrimp industry is centered at Rawson. This species forms the bulk of the export trade. However, the bulk of the catch is the common shrimp. This fishery is also centered at Mar del Plata where there are four shrimp-processing plants. The largest one can freeze over 450 metric tons of shrimp per month. This species is also canned. At this port there is also a fish concentrate plant, employing enzymatic proteolysis for the manufacture of a mixed fish and meat paste.

Japan has recently been aiding Argentina in the development of her fisheries. Through Japanese influence the industry has initiated skipjack (bonito) canning.

Lack of adequate refrigeration facilities, both at the ports and, more so, in the interior, has retarded the expansion of the frozen fish trade. Also in this field Japanese influence is felt.

Salted lingcod has been substituted in some places for the popular bacalao (salted cod). There is probably a chance for expansion along this line.

BOLIVIA

Landlocked Bolivia landed 500 metric tons of fresh-water fish in 1961. Lake Titacaca probably supplied the bulk, although Lake Poopo and the numerous lakes on the headwaters of the Madeira River and its tributaries are local sources. Since the quantity is not great, most is probably consumed unprocessed with some dried locally for winter use.

XIII. Southeast Pacific

CHILE

Chile's fish industry was not greatly developed until very recently. The Chilean government has undertaken a strong promotion campaign to increase fish consumption, seeking both an expansion and stabilization of the fishery industry and to improve the diet and nutrition of the Chilean people.

TABLE XII
SOUTHEAST PACIFIC FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Chile	32.2	64.6	155.0	339.7	429.8	638.6
Peru	—	47.7	179.1	3,531.4	5,243.1	6,830.0
Ecuador	1.8	3.4	12.2	43.2	60.2	52.4
Colombia	10.0	15.0	17.0	29.7	47.5	51.7

In the edible-fish industry, 41,000 tons of shellfish and 52,000 tons of other fish were used in 1961, compared with 20,000 and 46,000 tons, respectively, in 1951. Of this three fifths was sold unprocessed for local consumption, one fourth canned, one tenth frozen, and 0.7% dried.

The most significant increases in the past decade have been in the production of frozen and canned fish as well as in the export of frozen and canned crustacean shellfish, mainly centolla crab from the Humboldt Current.

CORFO (Government Development Corporation) is erecting a canning unit to produce annually 360,000 cases containing 48 lb. of sardines and a second line 400,000 cases of tuna and bonito. The freezing plant will have a capacity of 100 tons of whole fish per day and storage space for 1,000 metric tons of frozen fish. Finally, a reduction plant is being installed, designed to handle 30 tons of fish meal per hour, largely anchovies. This fish-processing complex will be manufacturing approximately one third each of (1) canned fish, (2) frozen fish, and (3) fish oil and meal. CORFO is also supporting the installation of additional large meal plants. South African, U.S., and Norwegian companies are partners in modern units being built at Iquique in northern Chile.

Several new fish meal plants have been built in the same region and several older ones have been re-equipped and expanded. The chief catch for these reduction plants is the "anchoveta," identical with the species caught off the coast of Peru.

PERU

Peru has become the third largest fishing nation of the world. The growth began about 1956 with the initiation of anchovy (anchoveta) fishing on a large scale for industrial purposes. About 5 million tons, 96.1%, of the 1961 Peruvian catch was anchoveta, the abundant raw material from which the major product of the industry, fish meal, is made. Other fish industries in Peru are fish oil, frozen fish, canned fish, and protein concentrates.

In 1961 there were 101 fish meal plants. In northern Peru, some 48 fish meal plants are reportedly in operation or under construction in Chimbote alone. In the course of the last two years, Peru has become the leading world supplier of fish meal. Exports of fish meal constitute the bulk of Peru's fisheries industry shipments, exceeding four fifths of the total (see tabulation).

FISH MEAL PRODUCTION AND EXPORT (1000 metric tons)

Production	1938: —	1956: 31.0	1959: 332.4	1962: 1,121.0
	1950: 1.1	1957: 64.5	1960: 558.3	1963: 1,380.0
	1955: 20.1	1958: 126.9	1961: 839.8	
Export	1956: 27.8	1959: 277.6	1962: 940.5	
	1957: 61.7	1960: 507.0	1963: 1,160.0	
	1958: 105.8	1961: 708.4		

[a] Compiled by the National Fisheries Society, Peru.

Many existing plants are doubling their facilities rapidly and numerous new plants will be coming into production within the next few months. With the increased capacity, another million tons could be added annually to Peru's fish meal production by 1964. The availability of fishing vessels is considered to be a limiting factor for such increases. Progressively larger vessels with increased range and speed are being built to help cut costs, but there are several signs of limitations in fish supplies reflected in smaller catches per comparable fishing effort. There are further annual fluctuations in stocks which some years are pushed out to sea due to deviations of the current along the coast.

Fish oil is a by-product of the fish meal production process, and has recently become important as producers seek ways to improve efficiency of operations and to reduce costs. In 1961 89 plants were producing crude oil with a production of 118,900 tons, an increase of 147% over the 1960 production of 48,200 tons. Peru has become the leading world supplier of fish oil also.

Except for the preparation of oil from turtles at Pisco and the capture of whales at Tumbes, there is no fishery for oils in Peru.

Freezing and Canning

There has been little change in the freezing and canning of fish which continue to be a small but important part of the over-all fisheries industry.

Seven plants produced 22,300 tons of frozen fish in 1961, an increase of 23% over 1960 production. About 90% of the frozen fish is exported, normally most to canneries in the United States, especially to Puerto Rico, which took 77% of the exports in 1961; the remainder went chiefly to Italy.

Bonito is the basis of Peru's canning industry. Some 80% of the fish canned in 26 plants along the Peruvian coast in 1961 was bonito. Of 24,000 tons of canned fish produced in 1961, 80% was exported.

The tuna-canning plants are closing because of depressed prices, high costs, and the more advantageous use of equipment in supplying anchoveta to fish meal plants.

Two Peruvian fishing companies in spring 1963 purchased a U.S. vessel ("Neva") for a tuna-canning factory ship. They plan to produce about 100,000 cases of canned tuna per month. In addition, this vessel has quick-freezing machinery and a cold storage facility.

This product may become increasingly important, not only because it can be spray-dried to produce a cheap dehydrated protein (or amino acids) but also because it appears to have excellent nutritive value.

Fish flour from anchoveta and anchoveta that is sun-dried and salted are both found to be excellent sources of protein in supplementary foodstuffs for the indigenous population, particularly in the Andes.

There are many other regional methods of preserving fish and fish products for local consumption, such as the dried eggs of the "voladov" or flying fish, called "cau-cau," which can be kept for about a year, or "charquecito," made from the congrio (conger eel). Congrios are opened, cleaned, washed in salt water, and hung to dry for 6–8 days. There are many other examples of sun-drying and salting.

Ecuador

The 1961 catch was 7 times the amount taken in 1952, and over 33 times the 1938 figure. This phenomenal growth is linked primarily to the intensified tuna fisheries of this coast. Practically half the landings is from the tuna group, 6.6% crustaceans, and 2.0% mulluscs. The remainder is miscellaneous food fish for domestic consumption, largely unprocessed.

In 1962, freezing plants started operation in Manta and Puerto Lopez chiefly for preserving the catches of small fishermen. The Development Program for Ecuador is implementing freezing plants and starting chilling facilities in the fish markets of major cities.

In 1963 the government granted a permit to a U.S. freezer ship to purchase fish in Ecuadorean waters for one year. The agreement provided for the owners to submit a plan for the establishment of a land-based freezing plant and a 5-year operating plan.

Japanese catches of tuna and shrimp will be sent to a freezing plant at Quito. The shrimp is later exported to the U.S. A U.S. supermarket company has installed a freezing plant in Ecuador and plans to buy there about 50,000 lb. per week of lobster and shrimp. A Japanese firm is to participate in the establishment of a processing plant for packing tuna and manufacturing its by-products.

Colombia

The 1961 catch was almost 5 times the 1938 catch, and over 1.5 times the previous high, landed in 1957. Although Colombia has a longer Pacific coastline than Caribbean, only about 6% comes from the west coast. The numerous bays and inlets along the north coast make good fishing grounds. The Magdalena River is an important source of the fresh-water fish which comprises two fifths of the total. The ocean perch group makes up almost two fifths, sardines one tenth, and crustaceans 4.2%.

Most (over three fourths) of the fish is consumed unprocessed, one seventh cured, and 6.9% for miscellaneous purposes. There are fish canneries in each of the three major fish ports, Cartagena, Baranquilla, and

Santa Marta. However, the total pack is small. There is also a freezing plant with 30-ton daily capacity, but storage facilities are not adequate.

Much of the fresh-water fish is salted on the spot under rather unsanitary conditions. Over two thirds is characids (Characidae) and one fourth catfish. In the shrimp fisheries, most of which are in the estuary waters near Baranquilla, 600,000–1,000,000 lb. are harvested annually. Much of this is exported.

The sea fish are usually caught within 20 miles from the coast at less than 100 fathoms. Japan has recently been surveying the nearby waters for tuna.

XIV. Middle America

BRITISH HONDURAS

The fisheries of British Honduras could be developed much further. The low coast has numerous lagoons with numerous creeks and rivers flowing into them and a wide continental shelf, factors that point to good fishing. However, since the population of this British Crown Colony is low, there has been little demand for fishery development. Most of the catch has come from within 20 miles of the coast by native craft. The majority is consumed unprocessed.

TABLE XIII
MIDDLE AMERICA FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Mexico	17.1	68.4	88.1	197.9	225.4	218.6
Guatemala	0.4	0.6	1.8	0.3	0.7	1.6
Panama	0.7	0.7	3.0	10.9	11.3	13.6

Fish caught off the offshore bays is largely salted and dried for the Belize (the capital) market. Spiny lobster tails are frozen and shipped to the U.S.

GUATEMALA

Most landings are classified as unsorted fish and most is consumed unprocessed. A joint Japanese-Guatemalan shrimp-fishing company was established at Champerico toward the end of 1961. In its first year the company produced about 590 metric tons of shrimp (heads off), shipped mostly to Los Angeles and New York. Base facilities at Champerico include a 100-ton capacity refrigerated plant and a quick-freeze unit of 12.5-ton capacity.

Other shrimp-freezing plants are now operating at Guatemala City and San José. The estimated shrimp production for 1962 was 900 metric tons.

An inland fisheries research center has been created at Barcena not far from Guatemala City. Serveral types of fish are studied here and can be profitably cultivated. Many lakes have been stocked for subsistence purposes and several farms have initiated pond cultivation.

Honduras

Almost nine tenths of the landings is marketed as unsorted, 8% is crustaceans, and 4% molluscs. Like most Central American republics the shrimp, which forms the bulk of the crustaceans, is mostly exported. There are three shrimp-processing plants, at Caratasca, Guanaja, and Puerto Cortes. The first two can each freeze 6.3 metric tons of shrimp per 24 hours and have cooler space for 56.7 metric tons of processed shrimp. The last has a capacity of 158.8 metric tons, but much of its space is used for beef.

Aside from about 40 miles on the Gulf of Fonseca, all of the coastline is on the Caribbean side and is low with numerous shallow lagoons that make good fishing grounds. The small native boats can be used without venturing into the open sea. Specialists maintain that the lagoons could be developed into very productive fisheries.

Many species such as mullet, shook, tarpon, snapper, grunt, etc. are found along the coast. During certain seasons anchovy, king mackerel, and Spanish mackerel appear in commercial quantities. Turtles are plentiful. Salting and drying are common methods of preserving fish. Farm cultivation of carp and guapote (*Cichlasoma managuense*) has been successfully introduced and is rendering good yields.

El Salvador

All fish was classified as unsorted and it is assumed that most was disposed of unprocessed. In addition, two thirds as many shrimp was caught. There are four shrimp-freezing plants, two at Puerto El Triunfo and one each at Puerto La Union and San Salvador. The larger one at El Triunfo can freeze 40,000 lb. of shrimp in 16 hours. Most of the frozen shrimp is exported.

The lakes are heavily fished and a number of farm fish ponds (more than 50) have started producing.

Nicaragua

Landing statistics are not available. Most of the fish is taken by small craft. Nicaragua has more than 190 miles of coast on the Pacific and about 280 miles on the Atlantic. In addition, Lake Nicaragua with an area of about 3,000 square miles is the largest lake between the U.S. and Peru. This lake is peculiar in containing the only known species of fresh-water shark. Most of the fish is undoubtedly consumed unprocessed. A second big lake, Lake Managua, is rated as capable of rendering 5,000 tons of fish per year, 40% of which would be first class quality. On the whole, Nicaragua has more than one million hectares of waters with good fish-producing potentialities.

In the last few years the shrimp-fishing industry has mushroomed. Most shrimp is exported. In 1961, 432 metric tons of headless shrimp was exported, mostly fresh and frozen, and 688 tons in the first 7 months of 1962. Freezing plants have been built at Corinto, El Bluff, and Puerto Somoza. There is a processing plant for spiny lobsters on Corn Island.

Costa Rica

One third of the catch is listed as unsorted. Crustaceans, mainly shrimp, account for another third, tuna represents over one fourth. An interesting feature is the fact that one tenth of the harvest is turtles. Aside from the tuna and shrimp, most products are consumed unprocessed. The turtles, hawkbills, and other species are kept alive in "kraals" or pens at Port Limon until sold. Some are shipped by air to the U.S.

The shrimp industry is based at Puntarenas on the Gulf of Nicoya on the west coast. This port is also the chief fishing port. Before World War II it was an important tuna base with one of the largest freezing plants in Central America and a cannery. In 1947–48 the "red tide" killed all the sardines along the coast so that bait for tuna was no longer available. Consequently its importance declined and the freezing plant was converted to shrimp processing. Sardines were re-introduced from Panama and the tuna industry is being revitalized. Most of the locally processed tuna is sold on domestic markets.

Shark meat is dried and salted along the northeast coast and shipped to the interior where it is sold as "dried fish, codfish-style."

Panama

A little above half (54.9%) the sea catch is marketed unsorted, probably caught by small fishing craft and sold locally. The rest of the catch is crustaceans, mainly shrimp.

The Caribbean coast is about 480 miles long, the Pacific about 770 miles. The major portion of the commercial catch is corbina (*Pseudociaena deliciosa*), red snapper, Spanish mackerel, grouper, pack, mullet, snook, and threadfin (*Polynemidae*).

Most of the shrimp is found on the Pacific coast, centered in the Bay of Panama. The main base is on Taboga Island. Most of the frozen shrimp is flown to the U.S.

XV. Northeast Pacific

The sea catch of the United States and Alaska and also of Canada is discussed in Section VII.

XVI. Northwest Pacific

JAPAN

Fishing has an ancient tradition in Japan and was a characteristic feature of the first inhabitants of these islands, the Ainus, who subsisted largely on shellfish in earlier periods and later developed extensive fishing of herring, salmon, etc. The Japanese islands are surrounded by an intricate series of currents, warm and cold, creating massive upswelling whereby active mixing of waters takes place. This favors conditions for good plankton production and indirectly for rich fisheries. The Japanese coastline is mostly irregular, indented by innumerable large and small bays. Several afford large areas of shallow water protected from the violence of the sea.

TABLE XIV
NORTHWEST PACIFIC FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Japan	3,562.0	2,431.4	4,659.7	6,192.5	6,710.5	6,863.7
North Korea	925.2	275.0[a]	223.0	604.6[c]	730[c]	840[c]
South Korea	838.3	285.2	259.4	357.2	424.5	450.4
China	1,500.0	490.0[a]	2,234.0	5,020.0[b]	—	—
Hong Kong	—	34.3	44.1	62.3	63.1	71.0
Taiwan	89.5	83.5	154.3	259.1	312.0	327.0

[a] 1949. [b] 1959.

[c] From Yearbook of the Great Soviet Encyclopedia.

As a result of damage to the nation's fishing fleets during the war, the catch was reduced to a low of 1.8 million tons in 1945. The industry managed, however, to make a remarkable postwar recovery. In 1952

JAPAN'S AQUATIC HARVEST[a]
(MILLION METRIC TONS)

Year	Catch	Year	Catch	Year	Catch	Year	Catch
1925	2.77	1945	1.83	1956	4.8	1960	6.2
1930	3.34	1948	2.45	1957	5.4	1961	6.41
1935	4.15	1950	3.09	1958	5.5	1962	6.86
1938	3.56	1952	4.50	1959	5.9	1963	6.70
1940	4.47	1955	4.91				

[a] Including seaweed, but not whales. The catches in the 1930's do not include the catches of the colonial empire.

the aggregate catch was 4.5 million tons, or more than the prewar record, and the catch has been steadily increasing ever since with a lull in 1963.

The fishing industry of the homeland is centered in some 3,200 villages distributed along the entire coastline of these islands. The large-scale fishing operations, which account for about a third of the total landings each year, are centered in the large ports.

The significance of coastal fisheries is consequently diminishing while long-distance fishing and pelagic fishing are increasing. This has affected the composition of the aquatic harvests. There is a notable decline in sardine and herring, while the catches of saury, mackerel, tuna, cod, and cuttlefish have greatly increased.

Offshore trawling was earlier concentrated in the East China Sea, Yellow Sea, and South China Sea but has in latter years extended to the entire Pacific and finally to all oceans of the globe. Japan is to an increasing degree depending on deep sea fishing operations. Fleets of large tuna ships, usually 200–400 tons, and trawlers constantly increasing in size (2,000–3,200 tons) are now operating in the Indian Ocean as well as the Atlantic.

Several catches have reached or exceeded the half million ton mark: squid, flatfish, horse mackerel, tuna (including skipjack), and saury. The sizable tuna catches are related largely to the general expansion of high sea fishing. This tuna is generally frozen for canning, while that caught in adjacent waters is taken for direct canning to inshore installations.

Total Catch of Tuna (1000 metric tons)

1955:	181	1959:	331
1956:	232	1960:	389
1957:	279	1961:	493
1958:	280	1962:	525

Japan's trawler fisheries in the early 1950's began an elaborate campaign to find new fishing grounds and this search has been pursued persistently. As a result several new grounds have been opened up for exploitation in the South Pacific, Indian Ocean, and Middle Atlantic.

A new fishery, that of *saury*, is actively carried on north of Hokkaido and Honshu and now holds first rank among fisheries in terms of economic returns. There are indications that overfishing is taking place, as 1963 was a poor year.

Most of the saury catch is canned and some is exported, but most is consumed in the homeland. Skipjack is eaten raw, boiled, or roasted; it is most valuable when processed into katsuwo-bushi (see below).

Fresh-Water Production

The extensive industrialization has caused the use of hydroelectric resources to the utmost and induced widespread pollution of both coastal and fresh waters. This partly explains the drop in the coastal catch and the drastic decline in fresh-water fishing. It is also felt in the rice fields where intensive use of artificial fertilizers and chemical sprays has affected production.

Floating Factories and Motherships

CANNING

Floating canneries preceded the present freezing trawlers. They were used early by the United States in Alaska. These vessels were equipped for canning and also for waste processing. They were, however, land-based. Japan started to move out to high sea fishing as early as the 1920's, and later entered into competition with the Soviet Union by catching and processing salmon off the Soviet Pacific Coast.

The tuna-canning factories also serve the King crab fishing and salmon fishing of the North Pacific. They are 5–8,000 tons and carry complete canning lines. They are in turn served by fishing vessels generally based in Hokkaido.

Due to Soviet objections, only a few Japanese factory ships are allowed in the Sea of Okhotsk for the catch of salmon and crab. This has forced Japan to long-distance fishing in the Bering Sea and for other than salmon in the Gulf of Alaska. Several Japanese trawlers have been catching crab in the Bering Sea. Motherships of 5,630 gross tons have come with catcher vessels, each of 400 metric tons. A second mothership operates with four such catchers and four portable so-called "kawasaki" vessels of 350 metric tons.

SALMON

The number of salmon-fishing mothership fleets in the North Pacific has been declining. In 1958 there were 16 such fleets; in 1963 only 11 Japanese fleets were seen in the North Pacific. Red salmon makes up 60% of the total catch.

North Pacific: Salmon Catch

Year	Total catch (1000 number)	Canned (1000 cases)	Salted (metric tons)	Frozen (metric tons)	Roe (metric tons)
1957	60,358	1,742	9,213	22,710	626
1958	49,798	1,567	5,429	23,032	822
1959	42,331	1,496	3,849	14,155	723
1960	26,424	1,221	2,099	12,117	501

Crab

About 6 Japanese mothership fleets with 79 catcher boats have been fishing for crabs in the North Pacific, apart from salmon and bottom fish. Five floating canneries served the Japanese catchers in the Sea of Okhotsk. Since 1960, both canneries and freezing vessels have fished the eastern Bering Sea and the waters off Alaska.

King crab is both canned and frozen, generally at different seasons.

Freezing

The extraordinary size and capability of the stern freezing trawlers employed in distant waters throughout the world by the great Japanese operating companies are highlighted by a new 2,500 ton class with freezing capacity of 214.5 tons of frozen fish. Several recent ships even exceed 3,000 tons (see further Volume IV, Chapter 11).

The fish factory ship "Shikishima Maru" (gross tonnage 10,150) has five refrigerated holds, a fish-meal manufacturing unit, and a salting room. About 230 tons per day of whale meat or fish can be frozen to —4°F. (—20°C.); 215 tons per day are placed in lots into 44 cabinets through which brine is circulated, and another 15 tons per day are frozen in a small plant provided with brine piping and an air blast system. The frozen products are stored in the holds maintained at —4°F. (—20°C.) by brine grid coils.

Most tuna ships are equipped with freezing facilities.

Multipurpose Units

Processing motherships follow the fishing vessels into the Bering Sea and the tuna fishing in the central Pacific. These factory ships are quite sizable, 5,000–20,000 tons. Besides extensive freezing installations, they may be equipped with processing lines for canning, fish meal production, and oil extraction. Leading this group of floating factories are those serving whaling fisheries.

A modern salmon fleet consists of (a) mothership of 7,000–10,000 gross tons, with a canning line of daily capacity up to 9,000 cases of salmon, a reduction plant for offal, and often a quick-freezing plant; and (b) 30–36 catcher boats of 75–85 gross tons, 280–400 h.p.

Among recent additions to the Japanese fishing fleet is a factory ship for freezing, canning, and processing of salmon and trout in the North Pacific. This also serves as a whale factory. It carries a fleet of 4–6 20-ton fishing craft transported on the foredeck or slung alongside on davits. Its maximum speed is 17 knots with a service speed of 14 knots.

Danish vacuum freezing units are reported to be installed on Japanese factory ships, operating from Angola, for processing shrimp and crab meat. These freeze-dried products will be marketed by a U.S. firm.

Transport Vessels

Transport ships, generally refrigerated, serve the fleets, pick up their catches, and carry food and other essentials to the widely spread units. One type holds 1,250 tons of fish, another is 6 times larger. Merchant ships of several nations carry fish from the bases to Japan.

Fish Meal Factory Ships

Several large newly built fish-meal factories of more than 14,000 gross tons joined the Japanese fishing fleet in the 1960's. They have an average velocity of 17 knots. This is the prototype of future fish-meal factories.

These fish meal factories have been operating in the eastern part of the Bering Sea in summer; in winter they have been dispatched to the waters of Southwest Africa, off Angola, or recently to Chilean waters. Fish meal operations have also started off the coast of northern Japan, comprising saury, herring, etc.

Bases

Japanese high sea fishing, in contrast to that of the U.S.S.R., is serviced by a world-wide net of bases and ports of transshipment. Besides storage facilities, these bases may have installations for freezing, canning, and waste utilization. This has held the Japanese fleet of factory trawlers and motherships on a more modest scale than that of the U.S.S.R. Approximately one fifth of their high sea catches is processed by motherships. The remainder passes through this global network of bases. The creation of these bases seems to be only at its beginning.

The globe is presently girdled by a large number of such operations at bases and transshipment ports, in almost every major region. In some 35 countries joint Japanese companies are registered for fishing and processing.

Utilization

Japan's fish catches total some 6 million tons a year, of which about 76% is made into canned, caked ("kamaboko" and others), soy-preserved ("tsukudani"), salted, salted and dried, and other processed products. It is therefore of importance in the manufacturing of marine products to maintain freshness of fish before landing and during processing.

The traditional methods of drying and salting remain the main methods of utilization of Japanese catches. In terms of original fresh weight the aquatic foods are taken care of in the following major channels and relative amounts:

Curing:	2/5	Canning: less than	1/10
Fresh market:	1/5	Reduction:	1/7
Freezing:	1/7		

The skipjack landings exceed 600,000 metric tons, the largest catch of this fish in the world. A large part is dried and salted, some fermented, and some canned, constituting an important export article to the Philippines and Singapore.

Japan has also the world's largest squid catch, around 650,000 metric tons. This is salted, dried, and to some degree made into various fermented products. A minor portion is frozen for use as bait.

Fisheries companies are currently diversifying production and broadening activities by canning meat, poultry, dairy products, and fruit juices, and by manufacturing sausages, mayonnaise, etc.

Ice and Chilling

Natural ice has been used through the centuries for chilling purposes. Now a large number of ice-making plants serve the fishing industry, some with a capacity of more than 100 tons a day. There are 5 factories producing more than 200 tons a day, and 25 factories producing 100–190 tons a day.

Freezing

Fish has been frozen for several decades, and frozen fish was actually available as relief food after the great earthquake of 1923 in the Kanto region. It has been increasing ever since, most rapidly in latter years, from an annual capacity of 300,000 tons in 1955 to over 600,000 tons in 1963. Japan is the second largest freezer of fish as human food next to the U.S.S.R. A number of trawlers are equipped with chilling and freezing installations. All ships for long-distance fishing have freezers or are served by motherships with freezing facilities. Frozen are (1) tuna for export (mostly for subsequent canning), and (2) cheaper fish for domestic use. Fish is also frozen for holding, thereby alleviating gluts on the fresh market. Frozen fish products are extensively used in the canning and manufacturing of fish sausages, fish paste, salted and dried products, etc.

Curing

Drying and salting have since time immemorial dominated the Japanese fish-processing industry and are still the leading methods for preserving catches of cod, herring, salmon, and mackerel. The drying plants are located largely in Hokkaido, where the catch is big in relation to the population. There are some 22,000 dehydration plants and 6,000 salting plants on this island, and 10,000 drying plants and 3,000 salting plants in the north of Honshu.

Drying

For a great sector of Japanese society, dried fish and shrimp are regular ingredients of the daily soup. For the rural population and several low purchasing power groups they represent the main sources of high quality protein.

Drying is frequently combined in conventional ways with salting, but more uniquely with fermentation, the chief product of which is katsuwoboshi (see below). A special Japanese feature is the additional preservation attained through boiling the fish prior to drying. Boiled fish preserved in soy sauce—"tsukudani"—is also an important item. This is done with "iwashi" (sardines). Some 80–90,000 tons are manufactured each year of this type of dried food—the Japanese sardine and the sand launce ("tobis"). Shrimp is dried both commercially and in the home.

The breakdown of the approximate annual production volume is as follows (1,000 metric tons):

Dried	50,000– 60,000	Smoked and dried	2,000– 5,000
Salted and dried	105,000–110,000	Salted	85,000–95,000
Boiled and dried	120,000–130,000		

Salting

Salting was quite common in the early days of the Japanese salmon activities in the Russian Far East. Both pink and humpback salmons were dry-salted in immense numbers. In 1915 no less than 50,000 barrels of pickled salmon were prepared in the Amur region, while the Japanese dry-salted about 6 million chum salmon including a few reds, and 80 million humpbacks or "salmon trout" as they are called in Japan.

Salt is now in short supply in Japan. Shoyu (soy sauce) with its high salt content serves this purpose. Several fishes (eel, salmon, etc.) are therefore preserved by adding soy sauce.

Katsuwo-bushi

Katsuwo-bushi is made by a combined smoking, drying, and mold-fermentation of skipjack flesh. Both in appearance and texture it resembles in its final form a stick of hardwood, hence the name "dried skipjack stick."

In addition to flavoring and dehydrating the fish, the mold aids in removing fat and in breaking down complex amino acids. The growth and scraping off of the mold, followed by sun-drying, are repeated several times. Mold growth ceases entirely when the flesh is thoroughly dehydrated.

Katsuwo-bushi is one of the most appreciated condiments in the Japanese diet. Shavings of the sticks are used to flavor soups called suimono and other dishes.

Canning

Canning industries started with the packing of fish (salmon, sardines) in the 1870's. The Sino-Japanese War (1894–95) and Russian-Japanese War (1904–05) gave canning an impetus at the end of the nineteenth century and beginning of this century. Many small canning plants were also built by the Japanese on the Kuril Islands, Sakhalin, and Kamchatka.

Canned tuna dominates the pack, followed by the new saury products. Among new tuna products on the market are (1) large tuna flakes in jelly, (2) tuna with vegetables, (3) tuna steaks, and (4) tuna in curry.

The present industry consists of 450 canners, half of whom specialize in marine products. The pack of around 25 million cases (48 cans) breaks down approximately in the following way:

Tuna, bonito	6.0	Saury	2.0
Salmon, trout	4.5	Mackerel	1.5
Sardine	3.0	Shellfish	2.0
Others	6.0		

Saury is the large new pack which was a newcomer on the scene in the latter part of the 1950's. Crab and shrimp canning is conducted in the Bering Sea on factory ships. Large can-making factories are operating in the islands.

Two thirds of the canned food output is consumed domestically; the rest goes overseas. The trend has been to retain a growing percentage of the pack for domestic consumption, leaving less for export, although the total pack has been increasing. Fish and shellfish continue to constitute the bulk of canned food exports, mainly salmon and King crab.

Fish Sausages

Due to the scare created against fish, particularly tuna, by the "Dragon" incident (see p. 629, Vol. II), new ways had to be found to save the unaffected fish for human food. This was the rebirth of the fish sausage industry. The product imitates meat sausages, using mainly (although not more than 50%) tuna and whale flesh together with other fish. Pork is frequently added as a fat, giving the product a little of the flavor of traditional sausages. Several different types are made. Presently there are some 70 enterprises registered as manufacturing this item. The production volume has grown from some 4,000 tons in 1952 to over

120,000 tons in 1963. A number of large-scale plants have been created with capacities of several 100,000 sausages per day, handling some 10–50 metric tons of fish per 8 hours.

This important industry has grown to its present impressive size largely since 1953–1955. Sausage factories have also become part of the Japanese development plans in other parts of the world. One plant is located at Willemstad, Curaçao. Others are being built in Guatemala, Ghana, etc.

Fish Jellies (Kamaboko)

Fish jelly is an original product of Japan, somewhat like meat loaf or sausage without casing with fish meat used instead of beef. Fish jelly, usually called "kamaboko," has long been favored by the Japanese. The word appears in the literature of 400 years ago. It has sometimes been translated as fish paste.

Kamaboko started to be made in many varied forms only 100 years ago, although at that time it was solely on a home industry basis supplying the demand of the neighborhood. The fish used for making kamaboko were not limited to one or two kinds as now, but any fish available and suitable for kamaboko seems to have been used. Most kamaboko plants are small units; some 30,000 are registered.

The cohesiveness of the jelly ("ashi") is due to retention of the water-binding capacity of the myosin. Fresh quality is a prerequisite for this. Less-fresh fish need a binder: starch, or the addition of polyphosphates to maintain the elasticity of the product; the quality of this product cannot match that of truly fresh fish meat.

Because of the rapid increase in the production of fish jelly, the raw material, especially the croakers, etc. caught in the sea west of 130° longitude, is getting scarce. New species such as rattail, conger eel, etc. have been tried.

As the demand for and production of fish jellies grew, the fish caught in nearby seas alone were not enough; raw material had to be sought afar.

Algae (Seaweeds)

Japan consumes 340,000 metric tons of marine algae per year, which amounts to about 5% of its total consumption of marine products, including fish, shellfish, whales, etc. The Japanese people eat about 10 g. (fresh weight) per capita daily. This amount may appear rather insignificant, but seaweed constitutes an important bulk material besides providing essential minerals and vitamins, including B_{12} accumulated on the surface by microorganisms growing there. The two most significant items are "kombu" and "nori." The former is dried tangle (*Laminaria* sp.) shaved or scraped from the fronds or cut into pieces and dipped in shoyu (soy sauce) for processing purposes. Nori is the dried fronds of red algae of the genus *Porphyra* sun-dried on a smooth surface and stripped off in sheets. Nori is particularly high in vitamin B_6.

Trade

Japan is the first ranking fish trading nation of the world in terms of earnings accruing from her 415,700 tons of fishery exports, although the volume of fish is slightly less than that of Norway.

Japan has regained most of her prewar markets, aided through the liberalization of imports by the U.K. which is the second largest customer for Japanese marine products exceeded only by the U.S.

Japanese export of canned salmon has grown in particular during the sixties, chiefly through heavy shipments to the U.K. The export of canned crab meat reached a peak in 1959, and then began to decline as a result of (1) growing domestic demand for canned crab meat, (2) competition on the United States market from Alaskan products, and (3) the large influx of Soviet canned crab meat into the European market.

Of the total canned food output in 1962, two thirds was for domestic consumption, and one third (14.96 million cases in 1962) for overseas sales. The trend has been to retain a larger percentage of the canned food pack for domestic consumption, leaving less for export, even though the total pack has increased. In one decade the export sales have dropped from 40 to 30% of the total.

Frozen fish has attained a notable position in Japanese foreign trade, no less than 0.25 million metric tons in 1963.

Frozen octopus and oyster are exported to the U.S. and Canada and have been growing in volume. They are used as bait for halibut fishing in Canada and Alaska.

Most of the frozen tuna imported to California for subsequent canning comes from Japan. The U.S. receives more than 60% of all Japanese exports of tuna. Regular deliveries have been made also to Puerto Rican canneries. The U.S. has further been a good buyer of swordfish and halibut steaks, black cod, and rainbow trout. The quality of the packs has vastly improved in latter years.

Imports. A surprising feature of Japanese foreign trade in seafood products is the emergence of importation during the sixties. A growing amount of shrimp is being bought in Australia, U.S., India, Mexico, Taiwan, and other places. The domestic manufacture of fish meal is no longer adequate for the growing animal production. To supplement her own sizable fish meal production, fish meal is purchased from Southwest Africa, Chile, and Peru.

Whaling

There was formerly an abundance of whales in Japanese waters, and a sizable hunting is still carried on in various northern waters. A third of the Antarctic whale catch is now in Japanese hands, with seven whale-catching fleets. Japan has in latter years acquired one Norwegian, two British, and in 1964 one Dutch, whale-factory ship.

Besides the oil which is largely exported (75–80%), much of the flesh is used as human food. It goes into fish sausages or other special products. Both whale and dolphin meat have been consumed in Japan for centuries. It is also cut into thin strips and eaten raw with condiments, similarly to fish and chicken.

Another edible whale product is the blubber. It is served raw or salted, often with a spicy sauce.

As early as the 1930's Japan dispatched her first Antarctic whalers accompanied by refrigerator ships with holds at a temperature of —25°C., in which the meat was transported home to cold stores. Most of this meat continues to be bulk-frozen today.

Development Program

The Japanese Fisheries Agency is preparing a broad, long-range fisheries management program covering roughly a 5-year period beginning with 1967, the year when all fishing vessel licenses become renewable. The announced purpose is to develop from an over-all viewpoint a coordinated management program for the Japanese coastal, offshore, and distant-water fisheries, which are intimately related to each other.

North Korea

Little information is available on the fisheries of North Korea. Formerly, like its southern counterpart, the vast majority of the catch was from the rich continental shelf which is rather wide in that area.

Like most communist countries, there has been an organized expansion in the fisheries. The program is probably not as grandiose as that of South Korea. Trawlers of 400–1,000-ton displacement are, however, being built in North Korean shipyards. A 7,000-ton freezing trawler is on order from a Dutch firm. This will be capable of freezing 100 tons of fish per 24 hours, and a blast freezing tunnel can handle 20 tons per 24 hours. The delivery date is given as December 1964.

With these new ships, North Korea expects to move out into the northwestern and southwestern Pacific.

According to Soviet statistics the catch exceeds 750,000 metric tons and consequently surpasses that of South Korea.

South Korea (Republic of Korea)

The government signed an agreement with France and Italy on 21 January 1963 for 159 modern fishing boats. France will supply equipment including vessel hulls and equipment, and Italy marine motors and other machinery. By an earlier agreement the same French-Italian enterprise would extend to the Korean government a $120 million loan for constructing 950 new fishing vessels with a total tonnage of 118,000 tons. Most of these will be built in Europe. The involved company is to train Korean fishermen and technicians and assist in marketing Korean fishery products throughout the world. It is predicted that the project will boost the annual South Korean catch to over 1 million metric tons. Modern facilities are being created at six ports for the proper handling and storage of the increased catch. The government also plans to set up a fisheries and marine industry center at a shipbuilding yard by installing refrigeration, ice-making, and processing facilities for fish and other marine products.

The most important species of fish in the South Korean catch are saury pike, horse mackerel or bluefin tuna, Alaska pollock, anchovy, yellow croaker, hairtail, shrimp, crab, and squid. Of the 1962 landings about two thirds was fish, one eighth squid, one tenth seaweed, and 4.5% shrimp and almost as many oysters and clams. Anchovies made up one seventh of the fish catch, over one eighth was hairtails and almost as many saury pike.

The South Korean fishery industry supplies an estimated 85% of the animal protein to the Korean people, as well as 20% of the total value of the exports.

Over four fifths of the catch is marketed fresh. The rest is cured, canned, or otherwise used. Fish is dried with or without salt.

Fish is frozen at sea in modern freezer trawlers at an average rate of 20 metric tons per day at —35°C. The fish holds maintain —20°C. At the end of 1959, South Korea had 67 ice and cold storage factories with the following daily capacities: ice-making 1,557, freezing 275, cold storage 8,415, and ice storage 23,652 metric tons. Only 27 quick-freezing plants were in operation with a daily capacity of 275 tons.

In 1958, South Korea had 38 canneries in operation with a capacity of 35 million cases or about 52,000 metric tons. Most are equipped with modern facilities. The daily capacity of individual plants varies from a minimum of 300 cases to a maximum of 1,350 cases for an 8-hour day. Tuna and saury are the principal species canned. Other species canned include mackerel, scallop, ear shell, topshell, sea eel, white and red clams, crabs, oysters, shrimps, and anchovies. Under a recent contract, tuna is also supplied to a U.S. packer's canning plant in American Samoa. Korea sells canned saury to Burma.

South Korea's 42 fish-oil plants are all quite small, having a combined annual capacity of only 700 tons. Sharks are processed for oil, and mackerel oil is being considered as a possible product. These plants produced 353 tons of fish in 1958.

Shrimp, squid, and oyster are generally sun-dried. There are now eight shrimp-freezing plants in the country. The U.S. is South Korea's best market for frozen shrimp. In addition to exports, over 10 tons of frozen shrimp are sold annually to United Nations' forces in Korea. The principal market for dried shrimp is Hong Kong.

China

The history of Chinese fisheries is an old one. Fish culture, presumably a Chinese innovation, dates back to 2,000 B.C. China is perhaps the world's leading fishing nation. According to FAO statistics the registered catch of fish in 1961 was 6.5 million metric tons, 2.5 million of this from fresh-water sources. Much local fishing from ponds and rivers is of a subsistence nature and never enters commercial statistics.

In the northwestern province of Tsinghai are a series of lakes which provide fish for that interior area. Most of the province is on high plateau 9,000–10,000 feet in elevation. Tsing Hai or Koko Nor, 2,300 sq. mi., is China's largest salt-water lake and the chief source of the fish. A road has been built completely around the lake and wharves and storage facilities have been constructed. Fishing is done all months of the year. Fish-processing plants have been built throughout the province and the surplus fish is sent to neighboring areas.

China's coastal fishing grounds extend nearly 6,000 miles and cover 436,000 sq. mi. Numerous varieties of fish, from salmon in the northern streams to croaker and tuna in the southern seas, abound in these waters. Assuming an average yield of 25 metric tons per year per square mile of water, over the continental shelf the possible yield in marine products from China's marine waters could exceed 10 million metric tons.

There are two fishing areas: the coastal area and the deep sea fishing area. The near-sea fishing areas are the waters on the continental shelf of the Yellow Sea, East Sea, and South China Sea. This total area embraces 1,350,000 sq. km. (511,100 sq. mi.); chiefly sedentary fish are caught in these waters.

The northern fishing area includes the banks and coastal waters of Antung, Liaoning, Hopeh, and Shantung. Waters along the Shantung peninsula permit dragging operations all year. In other waters, the cold temperature of the water makes dragging difficult.

The central fishing area includes the waters along Kiangsu, Chekiang, and the southern part of the Yellow Sea. In this area, the northern part has many shoals and the southern part is lined with many islets, such places favoring the growth of plankton and forming a center for fish-breeding and spawning. The waters around the Chu Shan Islands provide good fishing for this reason. When the fishing season opens, thousands of fishing boats work in this area.

The southern fishing area includes the waters along Fukien, Kwangtung, and the southern part of the East China Sea. Taiwan is located within this fishing region (see further p. 374). During the winter, the temperature of the water in the deep part of Po Hai and the Yellow Sea near the coastline of China reaches the freezing point. Consequently large schools of fish migrate south of latitude 30°N. and remain all winter in the warm sea region in the eastern part of the East China Sea, close to the warm current. Hence the best fishing in winter is in the East China Sea.

The South China Sea, excluding the continental shelves, and the Pacific Ocean off the east coast of Taiwan are good deep sea fishing grounds because of the warm current. These are the areas of fish migration. Tuna is abundant in the South China Sea and adjacent waters.

The fresh-water fishing consists of two types of activity: (1) pond culture operations and (2) ordinary fish catching. Over 19 million acres of rivers and lakes and 3.5 million acres of ponds and rice fields yield fresh-water fish, the most important being carp. The provinces of Kwangtung, Hunan, Kiangsu, Hupei, Chekiang, Kiangsi, and Anhwei are notable for fresh-water fisheries.

Fish culture in ponds is a significant farm sideline. A 1937 survey revealed that 410,500 acres of ponds were used for fish culture involving the full or part-time employment of 13 million persons. In addition to fish, fish fry is produced on a large scale for export or domestic sale.

Fish is consumed fresh or dried and salted, the fresh fish being generally consumed within a few miles of the point of landing. Ice is carried on the sea-going vessels and the landed fish are generally in fair condition. It is estimated that about 10% of the total production is processed. Development of a fish-canning industry is difficult because of the lack of large fisheries comparable to that of the salmon and sardines of the U.S. The yellow-croaker fisheries are the largest fisheries of China, but the fish is not suitable for canning; it constitutes the basis of important salting and drying industries. Fish and shellfish are dried, salted, and made into sauce in the provinces of Chekiang, Kwangtung, Fukien, Hopei, Kiangsu, Shantung, and Manchuria. Fins of shark, beche-de-mer, squid, jellyfish, scallop, awabe, etc. form specialties and important articles of domestic commerce.

Fishing operations are being rapidly modernized. The future expansion of fisheries includes modernization of fishing boats, use of nylon nets, electrification of communication, continuity of operation throughout the year, and increase in variety of products. Exploration of new fishing grounds, conservation of resources, etc. are also stressed. A number of modern trawlers are at present being built in Shanghai. They are equipped with telecommunication facilities, machinery for hauling in the nets, and fish-shoal detectors. To handle the increasing number of motorized vessels, fishing wharves in Lushun-Talien, Chousan, Shanghai, Canton, and elsewhere have been extended. Several new fishing ports have been erected. A whaling fleet is presently being built.

Hong Kong

Hong Kong, a British colony founded in 1841, consists of the New Territories and a number of islands. The primary product of the colony is marine fish from a fishing fleet of over 8,500 junks and 20 Japanese-type trawlers. At the end of 1962 Hong Kong mechanized 5,199 fishing vessels with loans from the Government Fisheries Development Loan Fund; over 90% are owner-operated. Croakers, tuna, sea bass, and shrimp constitute the major portion of the marine catch. Almost half the catch belongs to the mullet–sea bass group. Carp, mullet, oyster, and shrimp are cultured.

Fish is generally marketed fresh; however, the sailing junks often salt their early catch at sea to preserve it. The Hong Kong Marketing Organization is establishing a wholesale fish market in the Castle Peak area of the Crown Colony. It will serve fishermen using Castle Peak Bay as an anchorage and fishermen normally landing their catches at Cheung Chau and Tai Po. A substantial portion of the catch is salted and dried for export to Indonesia, Malaysia, Canada, and the U.S. No major attempts on a commercial scale have been made to market such manufactured products of the industry as glue, fish meal, or pearl essence.

Freezing of shrimp is conducted for export to the U.S. There are no plants in the Colony devoted exclusively to processing of shrimp. There are at least five cold storage plants which have quick-freezing facilities.

Shrimp are peeled and deveined manually. The meat is placed in freezing trays of 0.5-lb., 1-lb., and 5-lb. capacity. Freezing is done at a rate of 1 inch per hour at 26°F. or a 5-lb. block in 4 hours. The frozen blocks of shrimp are packaged in polyethylene bags, labeled, and placed in cold storage pending shipment. There is a small export of frozen red snapper fillets to Australia.

There are local food-processing plants which sun-dry shrimp and make shrimp paste or a flour used for making noodles and chips. There are no known shrimp-canning plants in the colony. Oyster meats are dried or processed into oyster sauce.

TAIWAN

Taiwan is situated in the semitropical zone. Washed by the warm Kuro-Shio Current, its waters are rich in migratory fishes. The fishing grounds consist of (1) the trawling grounds in the southern part of the East China Sea, Strait of Taiwan, South China Sea, and Gulf of Tonkin, (2) tuna-fishing grounds in the South China Sea, Sulu Sea, Celebes Sea, and Indian Ocean, (3) the mackerel, sardine, and skipjack fishing grounds northeast and east of Taiwan, and (4) sardine-fishing grounds in the southern part of the Strait of Taiwan.

Taiwan's fisheries are classified into four main categories: (1) deep sea fisheries, (2) inshore fisheries, (3) coastal fisheries, and (4) fish culture. There were 35 tuna long lines in 1960 (four of 350 tons, 15 of 100–200 tons, and 16 of 50–90 tons). It also operates, since 1962, 550-ton Japan-made tuna vessels in the Indian Ocean and hopes to export part of these catches to the U.S. A supply base has been established at Singapore. Tuna, spearfish, and shark account for about 10% of the deep sea catch. Whaling began in 1957 as a joint Taiwan-Japanese enterprise, based in southern Taiwan. Taiwan's progress in deep sea fishing is remarkable. The Taiwanese tuna fishermen supply Malagasyan canneries.

Inland fish cultivation is one of the greatest of the ancient Chinese arts and is being greatly expanded in Taiwan with much modernization and scientific study. Milkfish, tilapia, carp, and mullet are extensively raised in ponds and paddy fields.

Taiwan's fisheries have so far largely contributed to the sustenance of the island's population. Due to the lack of surplus fish, progress in developing the fish-processing industry has been slow. Most processed fishery products are for local consumption. Exports of frozen tuna, canned fish, fish-liver oil, etc. are in small quantities. Exports of frozen tuna amounted to 1,800 tons in 1962 and are expected to be 3,400 tons in 1963. Canned fish is also finding a market in South Asian countries.

About 25% of fisheries production in the island is processed, the most important product being dried-cooked fish. Other processed products, in order of importance, are fish balls, salted fish, canned fish, dried-salted fish, fish-liver oil, and shark fin.

Ice is used in quantity for fish preservation all over the island, excepting for a small part of inshore fisheries which use salt instead of ice. At the end of 1958, there were 158 refrigerating plants scattered over the island with an aggregate capacity of 1993 metric tons of ice-making per day, 60 metric tons of freezing per day, 15,000 metric tons of cold storage.

The major shrimp-fishing grounds of Taiwan are off its southeastern coast; shrimp is caught year round, but the best season is March–May when 50% of the annual catch is landed.

All shrimp landed is consumed locally. Large and medium shrimps are shipped with ice from producing centers to consuming centers. They are used mostly by restaurants and hotels; the price is too high for the average family. Small shrimp is consumed fresh or dried. Dried shrimp is processed by boiling and sun-drying. About 7% of the annual landings is dried. Freezing and canning of shrimp are negligible. The extent of mechanization in shrimp processing will depend largely on the prospect of export.

In 1957, 41,694 metric tons of edible fishery products were produced. Almost half of this was boiled dried fish, over one fourth fish balls, and over one eighth canned.

XVII. Southeast Asia

Philippines

In 1961, more than 39% of the landings of commercial fishing vessels came from the Sulu Sea fishing grounds, and 25% from the Visayan Sea. Manila Bay yielded about 7% of the commercial landings. By the end of 1961, 125,810 hectares of fish ponds yielded 60,824 metric tons of fish.

Table XV
Southeast Asia Fish Catch
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
South Vietnam	180.0[a]	—	130.0[a]	240.0	250.0	255.0
North Vietnam				—	—	—
Thailand	161.0	161.0	215.9	220.9	305.6	339.7
Burma	—[d]	—	100.0	360.0	360.0	360.0
Cambodia	—	—	45.0	150.0[c]	—	145.8
Philippines	80.9	195.1	353.9	465.5	475.7	504.7
Indonesia	472.0	420.0[b]	638.4	756.7	906.8	943.0
Malaysia	—	139.0	140.4	167.1	178.4	198.4
Malaya-Singapore	1.5	2.3	6.1	9.2	9.7	11.5

[a] All Vietnam. [b] 1949. [c] 1956. [d] —, not available.

Despite increases in gross annual fish production, the Philippines imported 74,630 metric tons of fish products in 1961, 94% of which was canned.

The Fisheries Commission of the Philippines has plans to establish a central fish market as well as regional piers for the distribution and marketing of fish. It has started a project calling for the construction of 16 fishing ports, 13 refrigeration plants, 51 fresh-water fish farms, and

20 brackish-water fish nurseries. Development of oyster farms and training of fishermen are included in the project.

More than half the catch (60%) is marketed fresh and the rest is cured or otherwise utilized. Sun-drying with or without salting is the usual way of curing fish. Small fish like dilis (*Stolephorus* sp.) are not salted or eviscerated before drying. They are given a quick wash with sea water at the beach, laid out in a single layer on long bamboo mats or oblong bamboo trays, and sun-dried for 2–3 days. Medium and large fish, such as *Mugil* sp., *Caranx* sp., *Rastrelliger* sp., etc., are salted before drying in the sun. After splitting the gills, viscera and blood are removed by a hard brush and the fish cleaned in sea or fresh water. Very large fish are filleted. The fillets are soaked in a 10% brine for about an hour to leach out as much blood and slime as possible. Each piece of fish is rubbed thoroughly with salt and packed in vats, barrels, or earthenware pots with salt between the layers and around the pieces. The ratio of salt to fish is 1:4 by weight. Within 2–7 days the fish are removed from the salt and brine, cleaned, washed, and laid on split bamboo mats and trays or strung on hooks suspended from poles. Drying is completed within 7–10 days depending on weather.

Wet-salting and then sun-drying are also practiced. The following species are treated in this way: *Rastrelliger brachysomus, Caranx kalla, Sardinella* spp., and *Leognathus* sp.

The fish are cured in concentrated brine for 2–3 hours, washed with sea water, and dried in the sun for 2–3 hours.

Small fish such as anchovies (dilis) and small mouth (sap-sap) are difficult to salt without some fermentation and protein hydrolysis taking place. "Bagoong" (fish paste) is a good example of small salted fish. Usually the free liquid from bagoong is skimmed off and used as a sauce ("patis"), while the semiliquid residue is ground, if necessary, and sold as bagoong. Some manufacturers, after the patis is drawn off, add saturated brine to the bagoong residue, let it stand a few days, and make another extraction of patis.

Patis is strained or filtered until it is light in color. Good patis may contain 9–10% protein.

"Dinailan" is a shrimp paste. Very small shrimp are dried in the sun for a day and ground in a mortar. The mass is dried and ground again for 2 more days, formed into cubes, and sold in the market.

Smoked fish or "tinapa" is a delicacy. Fish and shellfish, like barracuda, tuna, sailfish, sardines, anchovies, gobies, shrimp, oysters, etc., are smoked with considerable success. They are washed in sea water, cooked in a medium brine, sun- or air-dried to remove surface moisture, and smoked in baskets placed over individual fire pots.

The Philippines obtained two floating fish canneries from Japan under the latter's World War II reparation program. One is a 2,000-ton factory ship turning out 840 cases of 0.5-lb. cans a day.

The government is constructing a fish cannery in San José, Mindoro, which will produce 1,250,000 cases of fish, mainly sardines, mackerel, and anchovies. It will also produce fish meal. The plant will increase the country's fish-canning capacity by about 150%.

NORTH VIETNAM

Like many communist countries, statistics on North Vietnamese fisheries are not available to western scientists. From the little information gleaned from the literature, it appears that the government is trying to increase fish production to alleviate the protein shortage. It is well known that both China and Taiwan fish the Gulf of Tonkin and the South China Sea.

In 1959 the catch for the first half of the year was 40,000 tons, an increase of 25% over the same period in 1958. The Soviet Encyclopedia reports 97,000 hectares fish cultivation, rendering around 75,000 metric tons in 1961.

A fish cannery has been built in Hanoi with Russian aid.

SOUTH VIETNAM

The commercial fish catch has increased 69% in 4 years, an increase made possible by the continued mechanization of the fishing fleet and construction of ice factories in various fishing centers. Major achievements in the field of fisheries in 1961 were (1) the development of new export markets, (2) the discovery of large schools of threadfin (*Polynemus* sp.) further north than ever before, and (3) the undertaking of a survey of the nation's fishery resources.

Fish is generally marketed fresh. A substantial portion of the catch is sun-dried with or without salt. Very small fish are dried whole without salting. Comparatively large fish are eviscerated and incised. Salt is rubbed into the incisions, or salt and fish are placed in alternate layers. Since the salt used is crude and hygroscopic, redrying is required from time to time which, of course, reduces the nutritive value and flavor of the product. Brining is conducted in some areas. Roasted and ground rice are sometimes added to the fish before drying.

Nuoc-mam (fish sauce) is a staple item and important source of protein in the Vietnamese diet. It is more or less similar to the nam-pla of Thailand in regard to preserving and processing. It is a clear brown liquid rich in salt and soluble nitrogen. It is usually prepared from different kinds of small fish both marine and fresh-water. A method has recently been developed by the Fisheries Directorate for reducing nuoc-mam to solid form, which has important military uses.

Fish pastes are prepared by adding cooked glutenous rice, roasted rice, rice bran, and other cereal products.

A factory in Phan Thiet, one of the principal fishing ports of the country, processes canned sardines. Annual production is 5,000–10,000 cases, all of which are consumed locally. The company has plans to produce 50,000 cases per year, 30,000 to be exported.

There is one modern shrimp-processing plant in the country. However, shrimp is consumed locally, fresh or dried, and a portion of dried product is exported to Singapore and Hong Kong. The main center for shrimp fishing is Rach-Gia on the Gulf of Siam.

CAMBODIA

One of the best known flood fisheries in the world is on the Mekong River in Cambodia. During the rainy season a tributary of this river, Tonle Sap, flows backward and fills up the Grand Lake. As the Mekong waters recede, the Tonle Sap begins to drain the lake. Although fishing goes on in all seasons, the greatest activity is in the period of receding waters when the fish return to the rivers. The fish are dried, smoked, or salted; but the majority are fermented to make "nuoc-mam," a fish sauce, or "pra-hoc," a fish paste (see Chapter 8, this volume).

Four-fifths of the landings are from fresh water, while the rest are from the Gulf of Siam. Most fisheries are of a subsistence nature.

THAILAND

Fisheries rank next to agriculture in extent and value among the basic industries of the country. The marine fishing grounds of Thailand comprise three fourths of the coastal waters of the Gulf of Thailand and a long section of the eastern shore of the Indian Ocean between Burma and Malaya, the total length of the coastline being over 1,500 miles. Fresh-water fishing grounds comprise many large interior rivers, lakes, swamps, streams, and ponds, many of which are used for fish culture operations. Carp, tilapia, catfish, sea bass, and gouramies are among the cultured fishes.

Thailand is one of the leading fishing nations in Southeast Asia. Rapid increase in fish production in recent years became possible by mechanizing the fishing fleet, but most fishermen still work in the shallow warm waters of the gulf, inshore if possible, to escape the worst of the monsoon weather. They look mainly for the 6-inch chub mackerel or "pla-thu" (*Rastrelliger* sp.), which comprised more than 20% of the total catch in 1961. To encourage fishermen to venture into the richer waters of the outer gulf and the Indian Ocean, the Fisheries Department is conducting an extensive survey of previously untouched grounds with the help of a 300-ton research ship. A new port is being developed at Ranong, on the west coast of the Thai portion of the Malaysian Peninsula. Some 100 boats, from 10-ton smacks to fast 100-tonners, are operating there, bringing in 200 tons of fish a day from the unexploited grounds in the East Indian Ocean. The Government is building a modern fishing station where ships can tie up, auction their fish, repair their nets, fill up with fuel and ice, and be out to sea again in a few hours.

Modernization and expansion have become a necessary corollary to the country's booming population. Fish provides more than 70% of the animal protein of the rice diet of the Thais.

Nearly 60% of the total catch of fish is consumed fresh and the rest processed in various ways. The common methods for processing fish are sun-drying, salted drying, smoking, cooking, production of paste (kapi), fish sauce (nam-pla), fish and starch products, e.g., fish cake and fish crackers ("look-shin" and "kaocrieb"), and fermented fish. In addition, there are some small canneries, 2 fish-liver oil plants, 3 meal plants, and many cottage plants. There are 5 freezing and cold storage plants of different sizes and 49 ice factories.

Drying and salting are the two principal fish-processing industries of the country. Small fish are dried whole in the sun without salting. Large fish, pla-thu (*Rastrelliger* sp.), for example, are eviscerated, washed in sea water, salted or brined, and spread on bamboo mats in the curing yard to dry in the sun for 2–3 days.

Dried shrimp processing is considered to be an important industry. They are washed in sea water, boiled in water with or without salt for half an hour, and dried in the sun. On rainy days they are dried on a fire. They are then put into heavy sacks and shelled with the help of a wooden mallet.

Sea mussels are thoroughly washed and shucked by boiling. The meat is boiled again in weak brine for 5 minutes, and sun-dried.

Shark fins are cut out and put in the sun after washing. They are boiled to remove the cartilaginous material before drying.

Squids and *sea cucumbers* are eviscerated, washed in sea water, boiled for a few minutes, and dried in the sun.

Only fresh-water fish are *smoked*. Cleaned and eviscerated fish are strung on bamboo sticks which, holding 10–20 fish each, are placed on platforms and a fire is lit. The distance of the fish from the fire is about 3 feet. The product is called "pla krob" or crisped fish.

Cooking is employed mostly for fresh fish during the period of glut. This reduces transport costs and preserves a portion of the catch. They are gutted, cleaned, and dipped in saturated brine for about 30 minutes. Four or five fish are placed in a small bamboo tray and cooked in boiling saturated brine for 10 minutes.

Shrimp paste is made from shrimp as well as from small fish. They are washed, salted, and placed overnight in a basket with a weight on top. This presses out and drains most of the water. Next morning the mixture is exposed to the sun for partial drying. Then it is ground and exposed to the sun again for some time. The product is lightly packed in wooden tubs for a period of several months for ripening (partial fermentation). To make the finished product more attractive, safranin or fuchsin is sometimes added.

Nam-pla (fish sauce) manufacturing is a household industry in many fishing villages. The principal fishes used for this purpose are *Stolephorus* sp., chub mackerel (*Rastrelliger* sp.), and carp (*Cirrhina* sp.). Sometimes entrails are also used (see further Chapter 8 of this volume).

There is no commercial fish *canning* in the country. Some home-canning plants exist, that turn out pla-thu in tomato sauce and oil at the rate of one ton per day.

In Chumphon and Ranong, there are three continuously operating plants, each producing about 5 tons of dried *meal* per day. Along the coast there are many small fish meal units on the cottage scale. The annual production is probably 1,000 metric tons.

One *fish-liver oil* plant with encapsulating unit has been set up in Nondaburi under the supervision of the Health Department. The plant has a capacity of 450 kg. of livers a week, extracting on an average 25% of oil.

Fish cake (look-shin) is a rather popular fishery product in the country. The number of plants in Bangkok is more than 100. The fish, *Cybium* sp. for example, are headed, scaled, eviscerated, and boned. The meat is ground several times in a grinder, mixed with salt, and boiled or fried in oil. There are many varieties of product of different shape and taste.

Fish crackers are improved fish cakes. Two parts of fish are mixed with 3 parts of tapioca flour, salt 2–3% of the weight of fish, pepper 1–1.5%, garlic 2.5%, and water 20–25% of the weight of fish and tapioca flour. The product fetches a higher price if shrimp is used instead of fish.

The processing method for fish crackers is very similar to that for the fish cake: the ingredients are thoroughly mixed together, steamed, cut into thin slices, and dried in the sun.

INDONESIA

The catch is from marine sources as well as the fish (mostly carp) being bred in tamboks and rice fields.

Japan is establishing a tuna and bottom fishing base at Tandjung Periuk near Djakarta. Besides furnishing fishing vessels, Japan will construct freezing and other processing facilities at the base. Tuna would be exported to the U.S. by a Japanese marine products trading firm.

Fish, being the only significant source of animal protein, is generally marketed fresh; a lesser amount is cured. Drying and salting are the usual methods of fish processing.

Salting

Pindung is a wet-salted fish product. The fish are put in pots or cans and cooked with up to 50% salt by weight; spices and tapioca flours are sometimes added on cooking, and the product is put in earthenware pots or kerosene tins. Air is excluded as far as possible. It is transported to various inland markets. The product remains good for a few days to a few months depending on the amount of salt added.

Fish and shellfish are dried in the sun with or without pretreatment with salt. Small fish and shrimp are dried whole with salt. In Sumatra, shrimp is cooked for a short time in water with salt, sieved, and spread in the sun for 2 days. Shelling is done by thrashing.

Somewhat larger fish are headed, eviscerated, and salted. They are also brined in some areas. Salting is done in various ways, such as rubbing the fish with salt or putting fish and salt in alternate layers.

Fish Sauce or Petis

Petis is the cooked and concentrated liquor obtained from salting fish in various ways. The method of manufacture is similar to that for nam-pla of Thailand or nuoc-mam of South Vietnam.

Fish Paste or Trassi

It is manufactured from fish as well as shellfish. The fish are headed, eviscerated, and scaled. Water is removed from the fish by pressure. They are then salted, dried in the sun, and pounded in a wooden mortar to a paste. This is exposed to the sun in thin layers (for various trassi products see Chapter 8 of this volume).

Fish Cakes or Krupuk

Fresh cleaned fish (*Lates* and *Stolephorus* spp.) are mixed with an equal amount of tapioca flour, 20% salt, a few eggs, and sugar. The mixture is made into long rolls which are steamed, sliced, and dried into thin cakes. Sometimes shrimp is also used. The cakes are fried in oil before serving.

MALAYSIA

Considerable activities are evident for improving the deep sea and fresh-water fisheries in ponds and rice fields. The government has allocated over $2 million (U.S.) for development of the country's fishery and processing industry during its current second 5-year plan.

Fish is generally marketed fresh, but a substantial portion of the catch is salted and dried.

Small fish are cleaned of gills and entrails. Large fish are eviscerated and split into halves. All fish are rinsed in sea water before salting and placed in wooden tubs or concrete tanks containing brine. Salt is applied in 10:1 ratio. The salted fish are taken out in rattan baskets with numerous holes at bottom and sides facilitating drainage, rinsed with sea water, and drained.

Sun-drying of the salted fish is carried out on structures called planters. A planter is a platform of planks supported by poles planted in the sea or on the foreshore according to circumstances. Pieces of matting made of pandan (*Pandanus* sp.) leaves are spread over the planter and the fish laid out in a single layer. They are turned over several times in the course of the day. Sun-drying is completed within 2 days, depending upon the weather. Shark fins are treated similarly and dried in the sun.

Processing

A joint Japanese-Malayan firm is canning tuna at Penang, Malaya. The enterprise presently has a productive capacity of 500 cases of tuna a day, a quick-freezing capacity of 40 metric tons a day, and a cold-storage holding capacity of 600 metric tons of frozen tuna a month. It planned to expand the present cold-storage holding capacity to 1,200 metric tons a month by December 1963.

The tuna for canning are caught in the Indian Ocean by four Japanese fishing vessels, two of 100 tons and two of 150 tons. Approximately once a week one vessel returns to Penang with the catch. Three types of tuna are caught: albacore with white meat; yellow-fin and big-eye, both with light meat. Spearfish and marlin are also caught.

Aboard the fishing vessel, the fish are stored in refrigerated holds. On docking, the fish are transferred to the refrigerated warehouse of the canning firm with a capacity of 200 tons. These rooms are also used for the storage of sauries for bait.

The fish are taken out of the refrigerators and thawed. Chunks of meat are cut out and placed in wooden frames with wire bottoms. They are cooked in steam ovens. On cooling, the bones, dark meat, and skin are removed and the cleaned meat is put through a slicing machine. The slices are weighed and put into 7-oz. cans. Salt is added and the can is filled with cottonseed oil, soybean oil, or tomato sauce.

The firm prepares in addition 70 lb. of tuna sausages a day for local consumption, and half a ton of fish meal a day for poultry food. Finally, the company produces a small amount of tuna-liver oil, which can be added to the fish meal for enrichment or used in the manufacture of margarine.

The company exports its canned tuna to West Europe and the U.S. There is still no market for canned tuna in Malaysia.

Shrimping

Shrimping is conducted on a cooperative basis by coastal village fishermen in small sail or motor boats. There are no shrimping vessels. Most shrimp is consumed fresh. During glut, it is salted and exported to Singapore or Hong Kong. In 1959, export from the Federation of Malaya of crustaceans salted, dried, or simply cooked amounted to 292 tons.

Shrimp paste and fish balls are manufactured, but on a very small scale.

BORNEO

British Borneo is divided into three colonies: Brunei, North Borneo, and Sarawak. In August 1963 the latter two voted to join the New Federation of Malaysia, but Brunei abstained.

Most of the marine catch is landed by small native or Chinese fishing craft that sell their landings locally to be consumed unprocessed. Sarawak and North Borneo (Sabah) have no published statistics on their production, but Brunei landed 2,438 metric tons of fish and 255 metric tons of prawns in 1960. The small prawns and small fish are used for hog feed.

"Balachan" (shrimp paste) is made by mixing prawns and salt in a bag. The moisture is extracted by pounding and pressure, and the mixture is partially dried in the sun. It is then pounded with rice to a paste.

XVIII. Oceania

AUSTRALIA

Despite a 12,000-mile ice-free coastline, the fishing industry in Australia is small and relatively unimportant, employing only 0.4% of the total working force with 9,000 fishing craft of all sorts. Grounds near large population centers are already overfished and fisheries suitable for trawler operations are limited. It is difficult to provide cheap fish profitably; returns in relation to costs do not always justify the effort.

Stocks of estuary, onshore, and bottom fish are limited. The exploitation of extensive stocks of pelagic fish (such as tuna), crustaceans, and molluscs was until recently insignificant. Various species of fresh-water and marine fish, including both tropical and temperate, are available. The principal fish varieties caught are mullet, Australian salmon, jack, sea bass, tuna, barracouta (not to be confused with barracuda), flathead, snapper, whiting, and shark. Crayfish, shrimp, oyster, and scallop are also commercially exploited. Oyster, as well as prawn, cultivation is practiced in New South Wales.

TABLE XVI
AUSTRALIA AND NEW ZEALAND FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Australia	33.5	38.9	52.7	61.0	61.1	66.0
New Zealand	27.0	35.7	37.6	44.3[a]	43.1	41.3

[a] 1959.

More than half (66%) the catch is marketed fresh, the balance is frozen (16%), canned (13%), or otherwise utilized.

Processing

Very little fish curing and smoking are done, probably due to the scarcity of regular supplies of suitable species. In the past barracouta (*Thyrsites atun*) was used but is now marketed fresh. However, tailor (*Pomatomus pedica*), mullet, and fish roe are smoked in small quantities. In Tasmania kippered jack mackerel and smoked tuna steaks are produced.

There are a large number of small freezing establishments close to the catching areas. Distribution of frozen products is done by refrigerated trucks. Small refrigerated boats are being added to the fleets.

The fish-canning industry in Australia started in 1936. Today there are over 20 canneries in New South Wales, Tasmania, and western Australia. The principal fish species canned are barracouta, Australian salmon, and southern bluefin tuna.

Fish pastes are quite popular in Australia as sandwich spreads and are usually sold in glass jars or cans (2-oz.). They are manufactured from imported salmon and red herring as well as some small Australian fish.

For tuna chicken, the meat after filleting goes through a special preliminary processing followed by steam cooking in a retort. After cooking, the "chicken" is deep-frozen.

To make tuna ham, the fillets are dressed, brined, and smoked at 150°F. or more. This produces a desirable light tan color and delicate smoked flavor. The product is packed in 28-lb. cartons with grease-proof paper.

Most of the crayfish tails are now exported as the frozen product (see later).

Whale meat is frozen in small quantities for export to the U.S. to be used as mink feed. Whale oil is exported, 1.9 million gallons in 1961 as compared with 3.1 million gallons in 1959 and 2.3 million gallons in 1960. Most of this went to West Germany, the U.K., and the Netherlands.

In the southern states of Australia, the flesh of certain small species of shark is marketed in large quantities as a white-fleshed fish. Some attempts have been made to can this product.

A plant in New South Wales produces fish meal at the rate of 5 tons a day. The shark-liver oil industry is based on the school shark (*Galeorhinus rhinophanes*), whose liver oil yields approximately 20,000 I.U. of vitamin A per gram.

Trade

Even with its small population and low per capita consumption of fish (10 lb.) which may be due to an abundance of other foods, particularly of meat, Australia must import nearly half its annual requirements. About 90% of the imports are fresh, frozen, or canned; of the canned fish salmon, sardine, pilchard, and herring are the most important.

Despite difficulties in the fishing industry, a small specialized export trade has developed. Frozen crayfish tails, headless shrimp, and certain shellfish products have all (99%) been exported to the U.S. This export increased by 64% in 1961 over 1960. Fishing for pearl shell, trochus shell, and bêche-de-mer along the 2,000-mile tropical coast is important, but the return from the crayfish tails which accounted for £6.3 million (Australian) or 97% of all exports made them by far the most important fisheries export in 1961.

NEW ZEALAND

The important fisheries in West Coast Sounds and Stewart Island seem to have been depleted since 1956. Snapper, tarakihi, gunard, trevally, and blue cod are the principal fish species caught. Of the shellfish, crawfish and oysters are commercially exploited. Auckland, Wellington, and Timaru are the important ports where a majority of the catch is landed.

Tuna fishing in New Zealand is of recent origin. One canning company has bought a tuna trawler to fish tuna off the coast of North Island. A joint Japanese-New Zealand tuna-fishing venture was worked out in 1962. A canning factory was to be built at Rarotonga, Cook Islands.

A Nelson development company is trying to interest investors in building a fish cannery there to exploit some of the nearby fisheries.

Among the processed fishery products, frozen crayfish tails is the biggest dollar earner followed by frozen fish, canned fish and shellfish, and cured fish. Otago crayfish is exported to France, Germany, and Switzerland.

The crayfish tails are frozen raw as well as cooked. The cooking is done, in Dunedin, by lowering a steel basketful of crayfish into boiling water for about 10 minutes. They are then dipped into a tub of cold water for cooling, drained of surplus water, packaged in polyethylene bags, and quick-frozen. Three Dunedin companies are now in this business.

New Zealand must import fishery products. Though imports of frozen fish were banned in 1960, canned fish including herring, pilchard, sardine, and salmon, canned oysters, and salted and pickled fish are imported in large quantities.

South Pacific

Most of the thousands of islands in the South Pacific Ocean are inhabited but none is self-governing. The latest estimate for total production of marine products is around 23,000 metric tons. Of this quantity some 17,000 tons are tuna landed at New Hebrides, American Samoa, and Fiji. It is difficult to determine the exact amount caught; aside from tuna, most is caught by small native craft and disposed of locally. Whale meat is eaten on Tonga.

Perhaps the most important factor in the South Pacific area is the fishing bases for processing tuna. The American cannery on Samoa was the first to be built; now the Japanese have built or are building fishing bases at Espurítu Santo, New Hebrides; Noumea, New Caledonia; Papeete, French Tahiti; Si-Amilis, North Borneo; Rarotonga, Cook Islands; and Levuka, Fiji. Most of these have a cannery, refrigeration facilities, hospitals, and recreation areas, as well as living accommodations for the workers' families.

XIX. Indian Ocean

Burma

The majority of Burma's catch is from inland waters. Fishing is also carried on along the coastal regions of the Bay of Bengal and in the lower Irrawaddy Delta. Kyaukpyu Island, Ye Township, Mergui and Pyapon Districts are the large-scale fishing and processing centers. Coastal fishing is carried on mainly during the dry season (November to May) because of rough seas during the rains.

Fish is generally marketed fresh; a small amount is sun-dried and wet-salted. Very small fish are dried whole; large ones are headed and eviscerated prior to sun-drying. Hilsa is eviscerated, cut in the round, heavily wet-salted, and put in used kerosene tins or earthenware jars. Processed shrimp is mainly of three kinds: sun-dried after boiling, smoked or ground into "ngapi" (paste), and preserved with salt. A by-product of ngapi is "nganpya-ye" (fish sauce) and is the juice collected from the ngapi. Shrimp "brains" are preserved in sesame or peanut oil and marketed as shrimp oil. Shrimp and shrimp products are very popular.

TABLE XVII
INDO-PACIFIC FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Burma	—	—	100.0	360.0	360.0	360.0
India	—	816.9[a]	827.9	1,161.4	961.0	973.9
Pakistan	—	239.0[b]	259.9	304.5	319.1	330.6
Ceylon	—	24.0	28.8	57.8	74.0	83.9

[a] 1950. [b] 1951.

Research is being conducted on methods of improving food preservation, canning, and processing with the help of FAO. The establishment of standards and specifications for the manufacture of ngapi is the first step taken in food standardization in Burma. A commercial type of standard fish-drying chamber has been designed and is being put into operation. Small-scale shrimp-canning plants with a daily output of 300–500 cans are reported to be profitable.

Burma and Japan signed an agreement in 1960 to establish a joint fishing company. The Japanese firm will furnish the fishing fleet with two 240-ton motherships and 24 carrier and fishing vessels. The motherships will cure fish and shellfish and manufacture fish paste on board and will discharge the products at ports at intervals.

INDIA

India has abundant marine and inland fish resources. It has a coastline of about 4,607 km. (2,863 mi.) and a continental shelf of 259,000 sq. km. (100,000 sq. mi.) or more in area, offering considerable scope for establishment of fisheries. The Bay of Bengal and Arabian Sea abound in fishing grounds; gulfs and bays all along the coast and a large number of islands with their mangrove swamps and coral reefs are rich sources of marine fish. Tidal estuary waters in the mouths of large and perennial rivers, large brackish water lakes, backwaters, lagoons, and swamps scattered along the entire coastline, afford lucrative estuarine fisheries.

Vast stretches of fresh water consisting of rivers, streams, lakes, reservoirs, tanks, ponds, and paddy fields offer scope for inland fisheries. When added to other fresh-water resources, the total surface would run to several million acres of which not more than a million acres presently are under fish culture.

Fishing in Indian seas is generally confined to a narrow coastal belt 11–16 km. in width, and the richer offshore and deep sea waters are poorly exploited due to shortage of powered fishing vessels. A limiting factor is the coastal topography of the continent, with notably few natural harbors and few places suitable for construction of ports; this is frequently due to the shallow sand ridges along the coast.

Half the total fish landings is sun-dried, salted, or pickled for future consumption, but the curing processes are by and large unscientific and the product is inferior. However, cured fish makes up four fifths of fish exports. A major part of the landed fish spoil owing to inadequate transport and preservation facilities, and are used as manure or otherwise disposed of.

Two thirds of the catch is obtained from the sea. A 10-fold increase in fish production is considered necessary to meet adequately the demand for fish in the country. A beginning in this direction has been made with the employment of modern fishing techniques; trawlers and power vessels are replacing indigenous boats and smacks, and refrigeration units have been installed for preservation and storage of fish. Combined with this, the provision of quicker and better transport and marketing facilities is expected to result in increased fish production and improved trade.

A major commercial fisheries project has started at Okha Port on the Saurashtra coast of the State of Gujarat. This project envisages the employment of five medium mechanized vessels to exploit the shrimp resources of the Gulf of Kutch and two trawlers to carry on offshore fishing in the Arabian Sea. In addition, two transport launches are to pick up fish to be landed in adjoining fish harbors. The project will include the establishment of various processing lines for canning, freezing, cold storage, and manufacture of fish meal. Besides exploiting domestic markets in the principal cities such as Bombay and Delhi, efforts are directed toward the exporting of processed products to the U.S., West Germany, and other countries. The government has fisheries research stations at Port Blair in the Andaman Islands, Paradip, Mangalore, Bombay, Cochin, Tuticoren, and Visakhapatnam.

In December 1962 the Indian government opened the largest and most modern frozen seafood processing plant on the Asia mainland at Cochin on the southwest coast. It can produce 6–10 million pounds of products per season.

CEYLON

Ceylon has more than 140,000 acres (2,187.5 sq. mi.) of fresh waters and 300,000 acres (4,687.5 sq. mi.) of estuary waters, most of which have a potential for fish production. These resources have not been fully utilized. Inland fisheries consist mainly of the catching of natural stock by traditional methods. Irrigation reservoirs and village tanks, some built centuries ago, are not fulfilling their likely fish-producing potential.

The significance of developing these fresh and brackish waters through management and cultivation is known and stressed in most development plans.

The catches have been increasing rapidly in recent years. This was made possible by the mechanization of nearly 2,000 boats. Ceylon has an ambitious plan to increase the number of mechanized boats to 8,000 by 1968. A Navy training vessel is being converted to a research ship for studying the hydrology and basic productivity of the waters around the island.

It has ambitious plans to expand lobster and shrimp fisheries, extract agar from local seaweeds, hygienically manufacture dried fish, convert fish waste to fish flour, and study fish spoilage. Two fish harbors at Burewela and Tangalla on the west coast and another in Galle in the southern province are nearing completion.

Fish is generally marketed fresh. The manufacture of dried fish with or without salting is of considerable importance. Sun-drying without salting is limited to very small fish and shellfish like shrimp. They are dried whole on the hot sandy beach. Salting and sun-drying are applied to all other species. The fish are gutted, split, incised, and salted. The moisture is drained off, and the product is washed in sea water and sun-dried for 3–5 days. In some areas, untreated fish from large catches are buried under one foot of sand on the beach for up to 3 days before processing.

Salting and wet-curing with ultimate sun-drying are also practiced. Whole small fish and scaled, eviscerated, and filleted large fish are placed in barrels of concentrated brine, to which dried pericarp of goraka (*Garcinia gambogia*) is added. This ingredient decreases the sharp taste of the salt in the cured product. Salt is added repeatedly. In dry weather, small fish are removed from the brine and sun-dried during the day and returned to the brine at night.

Maldive fish, specially tuna (*Euthynnus pelamis*), are gutted and cut into thick chunks. A broth is made either by boiling offal, blood, and bones in half sea and half fresh water by weight or by boiling with goraka in half-diluted sea water. The chunks of fish are placed in the boiling broth for 10 minutes, removed, rolled in wood or coconut-leaf ash, smoked for a few days, and sun-dried.

There are cold storage facilities at Mutwal where two trawlers are based.

Ceylon and Japan entered into an agreement in 1955 which was renewed in 1961 for fishing tuna. The tuna is sold in Ceylon as fresh fish, but there are plans to freeze tuna, spiny lobster tails, and shrimp. The enterprise also plans to can 5 tons of tuna per day.

Under Colombo plan aid, the Canadian government has set up an ice plant and storage in Colombo. China and Poland are also offering aid in fisheries development in addition to the help already given by West Germany and the U.S.S.R.

PAKISTAN

Fishery is second only to agriculture in extent and importance among the basic industries of the country. The fish catch comes from two sources—marine and fresh water, the latter being two thirds (67%) of the total.

Fishing in Pakistan is a seasonal industry. During the monsoon months it is generally poor in East Pakistan due to squally weather conditions in the Bay of Bengal and the flooding of the rivers and inland reservoirs. Sea fishing is restricted to the coastal waters and the fishing boats go out only when calm weather prevails. It is conducted along the West Pakistan coast after cessation of the southwest monsoon, generally from the end of September through January. Among the important marine fish and shellfish are sardine, mackerel, sole, hilsa, pomfret, shark, and shrimp. Carp constitutes nearly half the total fresh-water fish marketed, being closely followed by catfish.

Although mechanization of fishing craft has been going on steadily, a major portion of the fish is still caught from country boats. The number of mechanized vessels was 344 in 1961, and has since increased to nearly 500. The government has built a modern fish harbor in Karachi, West Pakistan; three more are under construction, two in West Pakistan and one in East Pakistan.

Besides government efforts aimed at increasing the fish catch, improving the socio-economic conditions of the fishermen, and promoting exports, the FAO, the U.S. Agency for International Development, and Japan and Sweden are providing technical assistance in the development of Pakistan's fisheries. Pakistan Industrial Development Corporation, a government agency, requested the Japanese Overseas Fisheries Cooperative Association (JOFCA) to send a fishery survey team to Pakistan in 1962. The team surveyed the shore facilities and conducted coastal and offshore water surveys for about 40 days. If the survey proved promising, Pakistan would probably seek Japanese assistance in developing its fishing industry.

The provincial governments of East and West Pakistan have an elaborate fish culture program in inland waters. Fallow water areas are being reclaimed for fish culture. Exotic food fish like tilapia and common carp, which breed rapidly in confined waters, are being popularized.

Four fifths of the total catch is marketed unprocessed and the rest converted to processed fishery products. The means of fish transport are outmoded and are mostly head loads, shoulder slings, pack animals, bullock carts, country boats, pony carts, and camel-back. Private trucks, railroads, and steamers are also used in the transport of fish but none has chilling or freezing facilities.

Processing

Curing is the principal method of processing marine fish; most of the fresh-water fish is consumed fresh. Sun-drying without salting and dry- as well as wet-salting are the general methods of curing fish. Drying and salting are carried on as cottage industries, except at Chittagong and Karachi where they are "big business." Shrimp is dried without salt or boiled in light brine before being put to the sun. Shelling is done manually. Hilsa, mackerel, etc. are wet-cured.

The freezing and canning industries are of recent origin, and are primarily restricted to shrimp. There are 14 freezing plants located at Karachi, West Pakistan, with a total capacity of 140 tons of frozen shrimp per day, and their combined cold-storage capacity is about 4,500 tons. There are only two freezing plants in East Pakistan, one at Chalna and the other at Chittagong. The first has a freezing capacity of 5 tons daily and cold storage for 200 tons, the second 2.5 tons and 50 tons, respectively. There is one canning plant at Karachi with a capacity of 5,000 3¾–5 oz. cans per day.

In freezing and canning shrimp, peeling and deveining are done manually. Grading, freezing, and actual canning are mechanized. Labor being cheap, it is not expected that peeling and deveining will be mechanized in the near future. However, in one freezer trawler automatic shrimp-processing machinery, such as shrimp peeler, shrimp cleaner, waste separator, deveining, and grader, has been installed. The vessel's two holds maintain a temperature of —20°C. (—4°F.).

Fish Meal

In 1962 13,300 metric tons of fish went to the reduction plants. Fish oil is produced on a very small scale by cottage industries. Fish like sardines and mackerel are generally converted to meals during periods of glut. There were six fish meal plants in Karachi in 1961. Of these, two are modern reduction plants, and the others grind the sun-dried fish. Total estimated capacity is about 130 tons per day. The government plans to establish four more fish meal plants in the country—two in East Pakistan and two in West Pakistan. The fish-liver oil is extracted mostly from the hammerhead shark (*Sphyrna blochii*). This oil averages about 15,000 I.U. of vitamin A per gram, nearly 25 times as much as standard cod-liver oil.

Pakistan recently (1963) declared it would establish a whale-oil processing plant.

Kuwait

The fishery statistics of Kuwait are not available. Regarding fisheries trends, two companies have been organized to fish in the Persian Gulf area and possibly the offshore areas of the Sudan. One company plans to open in Kuwait a new privately owned fish market containing the most modern refrigeration facilities for the sale of both fresh and frozen fish. The company also hopes to supply large foreign oil companies in the area with edible fish. Regional distribution will begin with the Lebanon.

Shrimping is the only successful fishery in Kuwait. It has two active shrimp vessels which fish about 35–40 miles off the Kuwait coast. The only processing plants are those on board ship. The shrimp are beheaded, mechanically graded, and manually packed in 5-lb. cartons and blast-frozen aboard the vessels. The cartons are then packed in 50-lb. master cartons and stored on the vessels until transferred to ships in Kuwait harbor. Shrimping is conducted from August to May.

In 1960, shrimp processing for export was a monopoly of a single company. Another company, supported by a leading sheik with the help of a British firm, is currently engaged in shrimping in the entire Persian Gulf with the processing plant located south of Dubai.

Besides the successful shrimping, the company officials have based the founding of both companies on the expectation of large-scale fish processing including freezing, canning, and smoking of fish, production of fish meal, and extraction of fish oil. As conceived, the major part of the fish-processing aspects of the business would be based in Dubai.

XX. Red Sea

Some experts believe the waters of the Red Sea to have one of the richest fisheries in the world. They may also be the least exploited. The Ethiopians and the Yemeni are the two most important fishing nations in the area. Soviet and Japanese fleets have also entered these waters.

SUDAN

Although Sudan borders on the rich resources of the Red Sea, only 4% of the catch is from that region. Over nine tenths of the catch is from the Nile River system. The rest is composed of miscellaneous aquatic animals and residues. Most of the catch is consumed unprocessed but any dried and salted fish finds a ready market. Such processing is being encouraged by the government.

TABLE XVIII
RED SEA FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Aden	—	20.0	54.2	22.3	47.4	53.8
Ethiopia	—	—	5.6[a]	19.1	17.2	14.0
Sudan	8.8	11.4	12.9	16.5	17.3	18.6
Jordan	—	0.5	0.4	0.1	0.1	0.2

[a] 1954–55.

ETHIOPIA

For centuries the Ethopians were isolated from the outside world by the Moslems. Although the Coptic Church with its 100 fasting days per year on which only fish could be eaten should have promoted the use of seafoods, the mountainous terrain and lack of transportation tended to negate the Coptic influence. Then too the Italian conquest of Eritrea in 1882 deprived Ethiopia of her seacoasts. Upon federation of Eritrea with its old mother country in 1952, the interest in fisheries was revived.

The fisheries that are being exploited are close to the coast with two main centers, Assab and Massawa. The fishing is done mainly by small boats. Most of the sardine and anchovy catch is sun-dried on the beach by the catcher, and sold to the fish meal factories that grind it into meal for export. For the Massawa fishery in 1961 the fish meal processing accounted for almost seven eighths of the catch. The fresh fish for local consumption was only 3.2% of the catch; about one tenth was refrigerated for export, mainly to Israel.

With so many small fishing enterprises it is impossible to keep track of all the landings. All but about 100 metric tons of the reported catch was classified as unsorted.

SOMALIA

Information is scanty about the fisheries of these former Italian and British colonies. The U.S.S.R. has started a tuna cannery in the Las

Khorek zone of northern Somalia. This plant can manufacture 21,000 metric tons of canned fish per season. The daily capacity of the reduction plant is 15 tons and that of the freezing unit is 20 tons. There are also cold storage facilities for 800 tons of frozen fish.

In Alula, in the northern part of the country, a U.S. processor and distributor is establishing a joint fish freezing, processing, and marketing operation. This plant will cost about one million dollars and will be operated on an equal share investment basis.

JORDAN

Most of Jordan's 200 metric tons of fish are landed at Aqaba on the Red Sea. This port is equipped with a freezing plant and storage facilities for 700 tons of fish per year. Before the fish consumption can be increased in the interior, roads and a fleet of insulated trucks are needed. Most of the fish is consumed unprocessed.

YEMEN

Although Yemen has considerable potential for developing its Red Sea resources, fishing today is still conducted on a small scale with primitive craft and gear. Fish is an important constituent of the diet of the inhabitants of coastal towns and in areas around Hodeida, Mocha, and Salif.

The fishery statistics of Yemen are not available. However, the Yemeni fishermen catch kingfish, red snapper, pompano, and other varieties of edible fish. Shrimp, crab, and spiny lobster are found in the waters off the Yemeni coast. They catch and export a small fish ("wazeef") which seems to be a variety of sardine. Catching of wazeef is operated from Mocha and Khawkha.

Most of the catch is marketed unprocessed. Some is dried at Khawkha and sold throughout the southern Yemen. The fishermen generally take their catch to Amran or directly to Aden where the fish is dried and prepared for export. In 1959, the combined Yemen-Aden dried fish exports consisted of 2,575 metric tons, 83% of which went to Ceylon.

ADEN

Most of Aden's fish catch comes from the Arabian Sea. Fishing is seasonal and is intensified during the fall after the southwest monsoon is over.

Fish is mostly marketed unprocessed but some is cured. The city of Mukalla, the second largest in the protectorate, is establishing fisheries and processing facilities for both tuna and spiny lobster. A U.S. importing firm was reported to have made preparations in June 1962 to bring a

60-ft. refrigerated fishing vessel to Aden for commercially fishing spiny lobster. A New York City firm recently installed a small sharp freezer for spiny lobster, while the British Commonwealth Development Fund built a large freezer and cold storage plant for tuna.

XXI. Southeast Africa

EAST AFRICA

The former British East Africa is now divided into Kenya, Tanganyika, Uganda, and Zanzibar. The last consists of a two-island sultanate, off the coast of Tanganyika. It has recently established a Fisheries Development Company which is trying to broaden its economic base by expanding its tuna and salted and dried-salted fish products. Kenya is also developing her marine fisheries. Several hundred tons of dried shark and kingfish are imported annually from Arabia.

TABLE XIX
SOUTHEAST AFRICA FISH CATCH
(1000 metric tons)

Country	1938	1948	1953–55	1960	1961	1962
Rhodesia and Nyasaland	—	2.0	6.8	13.6	8.3	25.5
Kenya	—	—	16.3	12.6	13.5	18.4
Tanganyika	16.0	22.0	51.0	60.0	60.7	60.2
Uganda	—	11.0	28.0	68.8	68.5	71.1

The other three are closely linked with the Great Lakes of Africa. All three border on Lake Victoria, the second largest fresh-water lake in the world. Other lakes include Tanganyika, Nyasa, Rudolf, Edward, Albert, Kyoga, and Eyasi. Lake Victoria furnishes the bulk of the fish for all three nations. As much of the fishing is done by small native boats that sell their catch locally, it is difficult to estimate the landings. It has been estimated that about 100,000 tons are caught annually from Lake Victoria. Tilapia comprises the major portion of the catch.

By far the vast majority is consumed unprocessed. However, freezing facilities are being developed at Lake Baringo in Kenya; in Uganda there are processing plants on Lake Edward and Lake George, and a small freezing plant at Katunguru. At Katwe on Lake Edward there are permanent salting vats and hot smoking pits. Fish cultivation is extensively developed in some sections of Uganda. South of Mombasa, seafish are often lightly cooked before marketing. A recent survey showed that the canning of "dagaa" (*Linnothrissa miodon* and *Stolothrissa tanganicae*) from Lake Tanganyika was feasible.

In the northern Nyanza region of Kenya, fish ponds are common (there are more than 7,000); production reportedly averages 60 lbs. per 100 sq. yd. The potential, sustainable yield of Lake Rudolf is estimated at 20,000 tons of tilapia and Nile perch together.

Rhodesia and Nyasaland

One would never expect a landlocked country to depend much on fisheries, yet this Federation landed 8,300 metric tons of fish in 1960, from the large lakes in this area. The four largest are Tanganyika, Nyasa, Bangweulu, and Mweru. In addition the dam on the Zambezi River in the Kariba Gorge created Lake Kariba, the largest man-made lake (2000 sq. mi.) in the world. Lakes Nyasa and Mweru are the most important fisheries. Conservation scientists, however, feel that Lake Kariba has a substantial potential for future fish raising.

The sardines of Lake Tanganyika find a ready market when dried. Unless the Nile perch are also caught and utilized, some experts feel that they (the perch) will deplete the sardine population through predation.

Most of the non-sardine fish is eaten fresh. Government officials are experimenting with a number of processed products, such as non-sturgeon caviar and smoked burbot.

The Tropical Products Institute (U.K.) in Nyasaland has tried the canning of fish from Lake Nyasa. None of the three dominant fish was regarded as suitable for canning. After processing, flesh texture was poor and the bones inadequately softened.

Malagasy Republic

The waters around the island of Madagascar have long been known for their abundant fauna. The Japanese and Taiwanese have been making regular trips to this area. However, the Malagasyans do not take advantage of these waters; the total catch in 1961 was only 4,000 metric tons. This is undoubtedly only the marine catch, since the production from fish cultivation is 22,000–25,000 tons per year.

Most of the catch is consumed unprocessed, a little is smoked or salted. Nonetheless, a French canning company has opened small canneries in Majunga, Diego Suarez, and Tamatave to ascertain if tuna can be processed profitably. This firm has contracted with Taiwanese fishermen for their supply of tuna.

A Japanese enterprise has freezing facilities at Majunga and Tamatave where shrimp is purchased from the local fishermen, frozen, and exported.

Sea cucumbers (holothurians) are abundant along the west coast and constitute the basis for a regular export to Hong Kong. Some are extracted off one of the Comoro Islands at the north end of the Mozambique Channel.

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Fish Meal: Manufacture, Properties, and Utilization

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I. Introduction

The primary utilization of fish should doubtless be as food for human beings. Fishery being, however, either seasonal or fluctuating, the yield varies within wide limits. During periods of great abundance, it has up till now been impossible to preserve the surplus of this very perishable raw material in a state fit for human consumption; hence the industrialization of excess fish in the manufacture of oil and guano, and later "fish scrap" and fish meal for animal feed. The manufacture of an "edible" fish meal is so recent a development that it has hardly gone beyond large-scale experimentation.

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In the following pages a general picture of the fish meal industry will be given. The basic principles will be explained; the most important industrial methods will be described and also some new principles that may prove of interest in its future development. Search for improved methods continues. The aim is not only to raise yields which in the early days of the industry were exceedingly low, but also to meet the increasingly rigid requirements for a product of superior quality. Statistical information on the fish meal industry is presented. The properties of the meal will be discussed, mainly its nutritive value in relation to manufacturing details.

The literature on fish meal manufacture is remarkably scant.

II. Preservation of Raw Material

A. GENERAL

With the manufacture of more valuable products it became necessary to give more attention to the quality of the raw material. This was even more necessary when the product was offered to the food industry. Preservation presented quite a problem. In many fishery districts it was out of the question to provide "reduction" capacity to cope with the peak landings. Raw material had to be left in storage bins to be worked off gradually. In northern Europe, notably Norway, the main season is winter and putrefaction is considerably retarded by the low temperature; even so the fish cannot be kept very long before serious deterioration sets in.

Sprinkling with salt was long the only means of prolonging the useful life of the raw material. The salting of herring has thus been very helpful and has been widely used for short- and long-term storage. But if fish were to be kept for longer periods, the use of salt had serious inconveniences. Firstly, an addition of up to, say, 4% salt meant heavy extra cost. Next, the preservative action of salt is only relative; after a while the raw material starts to decompose. It becomes difficult to treat in the reduction plant, yielding a dark oil with high acidity and a meal with an appreciable amount of free ammonia, a sign of incipient putrefaction. The salt content of the meal would be rather high (8–10%) and modern "whole meal" production would have been out of the question. All the salt added in this process is found in the finished meal; a mild preservation with, say, not more than 2% salt would give a meal with about 10% salt. For this reason the use of salt has now been largely abandoned.

The decomposition of the raw material for fish meal manufacture is caused by both bacteria and digestive enzymes from the fish intestines. Aerobic proteolytic bacteria are very active, while some of the anaerobic ones are less dangerous. It is therefore often observed that the raw material keeps better in the center of large piles than on the surface. The activity of the microbes increases very rapidly from 0°C. up to about 25°C. Above this temperature the spoilage is caused largely by enzymes. This action can be very rapid indeed, 24 hours sometimes being sufficient to convert a bin of sound fish to a soup or a porridge impossible to handle in the factory.

Preservation of fish for meal manufacture is made easier by the fact that fairly great amounts of preservative may be used. The fish reduction process is a very drastic one; quite a few added volatile or easily decomposable compounds can thus be eliminated. The question of total cost, however, must of course be considered.

Thus a great number of compounds have recently been tried, chlorine, chloramine and other chlorine compounds, sulfurous acid, benzene, etc. But only two have proved to be of real use, namely, formaldehyde and sodium nitrite.

B. Formalin

The addition of formaldehyde solution remarkably improves the keeping quality of fresh fish; the effect is of course largely dependent on the prevailing temperature.

In order to obtain even distribution, the commercial 40% product should be diluted at least 1:2 and added by means of a mechanical spreading device. The amount of formaldehyde needed—of the order of 0.5 gallon per ton—varies with the temperature, the raw material, and the required storage time. For short-term preservation up to a maximum of a fortnight at temperatures up to 15°C., formaldehyde alone has proved an excellent preservative. It not only checks the putrefactive bacteria, but also has a most beneficial action on the soft tissue, rendering it more easily pressable after cooking. For longer periods of preservation, however, this hardening action on the skin, especially on coarse raw material, can be a great inconvenience. Formaldehyde is indeed seldom used alone, and most often in combination with nitrite.

C. Sodium Nitrite

This compound, due to its bacteriostatic properties and the ease with which it is eliminated during fish meal manufacture, is a most valuable aid to the industry. Its bacteriostatic properties have been very carefully investigated by Tarr (1943). Its extensive use in the fish meal industry dates from investigations by Notevarp and Bakken (1955). Sodium nitrite is a poisonous substance; for this reason the preservation must be conducted in such a way as to leave only traces of the compound in the finished meal. In Norway the limit, for home consumption, was for long fixed at 0.02%, twenty times less than the dose where the first biological symptoms could be noted. Actually its use is subject to further technical and biological investigations. To preserve raw fish effectively for a period of several weeks, as much as 2–3 lb. nitrite per ton of fish may be needed; if all this nitrite passed into the meal, a product with quite a prohibitive dose of preservative would result. A number of happy circumstances tend to reduce the quantity of nitrite, and these processes start in the fish storing bins. The amount of nitrite to be used must therefore be carefully calculated according to the storage time and the prevailing temperature. This requires considerable experience, but can be worked to a very fine degree of accuracy. Most of the remaining nitrite will be eliminated during the reduction process. During cooking of the fish, no such reduction takes place, while the drying process and the stick-water-concentration process decompose most of the nitrite left. Then during storage of the meal the remaining nitrite can be completely eliminated, but as this process is slower a thorough control during preservation with sodium nitrite is needed to avoid complications. It is then possible to store the fish for several months without detriment to the finished meal. The nitrite may be sprinkled over the raw material with good results, as it has a remarkable facility of diffusing through the whole mass. But in practical operation it is always added in solution by means of automatic devices which assure very uniform dosification. While the bacterial decomposition is very effectively counteracted by nitrite, enzymic processes continue and after some time the raw material will contain considerable quantities of soluble protein. This seldom interferes with the manufacture. The raw material usually keeps sufficiently firm to be worked in the ordinary cooking-pressing installations. The use of these modern preservatives in the fish meal industry has proved to be of great advantage. The resulting meal is of excellent quality; it is free of putrefaction, as indicated by smell and taste and as measured by volatile nitrogenous compounds. The color of such meal is slightly more reddish when newly produced. The oil resulting from the preserved raw material is also first grade, the nitrite and/or formaldehyde having checked the formation of off-color and free fatty acid. It might be expedient to repeat, however, that *the preservation of fish with these ingredients must be carried out under the strictest control.*

III. Principles of Manufacture

The simplest way of manufacturing a fish meal would be to mince the raw material, and then allow it to dry naturally or by artificial means. Only in the case of very lean fish, offal from canneries, or heads and bones from stockfish manufacture and the like, can an acceptable product be manufactured in this way. In order to understand the whole process of rational fish meal manufacture, it will be expedient to consider the quantitative composition of the raw material. The matter will be simplified in the following example by assuming a raw material of the following composition, using round figures.

Per 100 lb.:		
Water		68 lb.
Fat		12 lb.
Nonfat solids:		
Protein	16	20 lb.
Minerals	4	

The biggest yield of meal from this raw material is obtained by simply drying off about 65 lb. water. The remainder will then have the following composition:

Water	3.5 lb.	(~ 10%)
Fat	12 lb.	(~ 34%)
Nonfat solids	20 lb.	(~ 56%)
	35.5 lb.	

Such a product would contain far too much fat to be salable. Furthermore, no valuable oil would be recovered. A process implying direct drying is therefore practical only with raw material containing 2% fat or less.

Another drawback of the above process is that it is necessary to remove by drying an amount of water equal to about twice the weight of the finished meal—in our example $68 - 3.5 = 64.5$ lb. This is an operation which involves heavy fuel expenses.

For these reasons the manufacture of meal from fatty raw material always starts with a precooking process followed by a pressing operation of the cooked stuff. During heating the protein matter is coagulated, the mass can be pressed and, if the cooking has been carried out properly, a press-cake with as little as 55 or even 50% water can be obtained. Equally important, during heating the fat cells containing the oil are ruptured, and a good yield of oil is obtained when the liquid is separated from the press-cake.

A reduction in moisture content from the original 68% down to 50% in the press-cake may not appear very significant. But recalculated into pounds of water per total weight the result is nevertheless astonishing. Together with the press liquor about one-fifth of the fish solids are lost, this proportion of solids being soluble in water. The press-cake will then consist of only 16 lb. nonfat solids. Assuming a residue in the cake of about 2 lb. oil, i.e. 5.5%, which is somewhat high but quite a common figure, the press-cake will have the composition given below. The composition of the finished meal is also given.

	Press-cake	Meal
Water (lb.)	18	2
Fat (lb.)	2	2
Solids (lb.)	16	16
	36	20

Of the 68 lb. water originally present, 50 lb. has been removed in the pressing; only 18 — 2 = 16 lb. needs to be removed by evaporation during the drying process. This represents a very considerable saving in fuel expense. One may get by with only one quarter of the fuel, and yet end up with a prime low-fat meal and 10% yield of oil.

These advantages have been bought at the expense of 20% of the total solids, a very serious reduction in the meal yield. The actual figure is in effect still larger, as only 20 lb. meal is obtained as against 35.5 lb. by direct drying. But 12 lb. of this latter amount is fat which is not desirable in the feed. Indeed, the meal is valued according to its protein content only, and the 12 lb. fat will therefore, for the manufacture, represent a loss.

Many efforts have been made to recover the losses due to the glue-water, or stickwater as it is termed in the United States. Such recovery started only 10–15 years ago on an industrial scale, beginning by concentrating the glue-water to a paste with about 50% solids content. This product is manufactured and sold as such under the label, "Concentrated Fish Solubles," or incorporated into the meal by mixing with the minced press-cake before drying. This is the product now known in Europe as "whole meal." The manufacture of such whole meal gives about 20–25% higher yield.

IV. Manufacturing Methods

The bulk of all fish meal produced is processed after precooking and pressing the raw material. Simple and primitive methods have been described by the present writer (Sparre, 1953). Mechanical devices are now indispensable in plants of all sizes and will be reviewed below.

A. Handling of Nonfatty Raw Material

1. *Simple Direct Drying*

The raw material, consisting of fresh fish offal from freezing plants and salting establishments, is cut in a disintegrator and passed through a so-called flame dryer. This consists of a steel cylinder mounted on trunnions, given a slow rotation. Inside the cylinder, longitudinal flights lift the material and allow it to fall through the path of the hot gases passing through the dryer concurrently with the meal. After leaving the dryer the meal is ground, cooled, and sacked, thus completing the process.

This method can be used for most nonfatty fish. The dryer must be able to withstand high temperatures. The gluey water that is released upon heating is likely to cause difficulties unless the inlet temperatures are very high.

2. *Drying with Recirculation*

As was mentioned, the crude material when coagulated by the heat sets free large amounts of gluey water which cause the material to stick and cake together, forming lumps that adhere to the heating surface and interfere greatly with efficient drying. By pressing the mass, the subsequent drying takes place without inconvenience. But if it is desired to avoid the pressing operation, the difficulties can be overcome by recirculation of part of the dried material. The minced fish then enters the dryer intimately mixed with a portion of already dried meal. This forms a semidry feed which gives no trouble in drying! It is often an advantage to dry in two steps—two dryers placed in series. Part of the semidry material from the first dryer with, say, 30% moisture is recirculated. In this case a high percentage of admixture is needed. If, for instance, the original raw material contains 80% moisture, an amount of recirculated material equal to 1.5 times the weight of raw material is required to obtain a mixture with about 50% moisture. For some raw material it will be found necessary to use a much higher proportion of admixed product. As calculations show, a proportion of 1:5 still gives a mixture with 38% water. Such a mixture can, however, be dried in the flame dryer very easily.

When working with fattier raw material, it may be an advantage to press the warm semidry mass before completing the drying. This will yield a less fatty meal but will, on the other hand, give rise to loss of solids with the press liquid. In other words, we have here a transition process to the orthodox wet rendering.

B. OLD REDUCTION METHOD

We shall now briefly describe this process, but it will be unnecessary to enter into details regarding the machinery used. Only the more important characteristics will be mentioned. Essentially the process consists of cooking, pressing, and drying operations, with separation to recover the oil from the press liquid.

During the early period of the industry, the manufacture consisted of a discontinuous batch process (see Anonymous, 1945). The raw material was cooked in open vats with direct steam. After some sort of preliminary draining the cooked mass was wrapped in burlap cloth and pressed in hydraulic presses, or even simple screw presses. The drying of the chopped press-cake was soon carried out in continuously working mechanical dryers, cylinders heated externally, in flame dryers with the stuff to be dried in direct contact with the fuel gases, and indirectly in steam-heated ovens.

Figure 1 is a flow sheet representing the fully developed process including glue-water recovery (see under C "Whole Meal"). The fish are here fed into a continuously working cooker, commonly a long horizontal cylinder fitted with a transporting screw and a number of inlets for direct steam along the total length of the cylinder. The mass is thus gradually heated to about 100°C., this temperature being reached at the outlet.

The cooking is a key operation. It is essential that the material be properly coagulated during the cooking; if not, a lot of trouble is experienced during the pressing. A badly coagulated material will give a press-cake with excessive moisture and fat content, while the oil separation of the press liquor will be difficult and incomplete. Often the press will not "take" the badly cooked material; a soft fluid mass oozes through the perforations. Various raw materials require different cooking. It should be noted that the coagulation is a function not only of the temperature but also of the time. Duration of the cooking must be such as to give sufficiently long contact, say 15 minutes, between inlet and outlet.

Old, partly decomposed stuff is difficult to handle, but too fresh fish also cause trouble. Very often the addition of coagulating agents will be found helpful. Calcium chloride has been widely used for this purpose. It has the inconvenience of forming lime soaps with the fatty acids, clogging screens and presses. For this reason formaldehyde is now most commonly employed; the continuous addition of a few pints per ton often converts the most difficult raw material into a perfectly coagulated product, ready for the press. During cooking all the live steam added of course condenses in the mass. This is therefore diluted with some 15–20% of water. As long as the press liquor went to waste this was of no great consequence. But the cooked mass contains so much liquid and also so much fine sludge, that it has to pass a prestrainer before it can be fed to the press. The sludge especially creates great difficulties in the pressing operation, since it clogs the pores of the press-cake. This sludge is effectively recovered in the sludge centrifuges, designed for this purpose. By putting in a rotary screen, with perforations of about ¼-inch, it is in many cases possible to increase the press capacity 100% or more.

There are different types of continuously working screw presses, with single or double screw, strainer surface of perforated plates or rods, etc. During transportation through the press cylinder the moisture and dissolved solids together with the oil, and an inevitable amount of suspended matter, are squeezed out. A satisfactory press-cake may contain

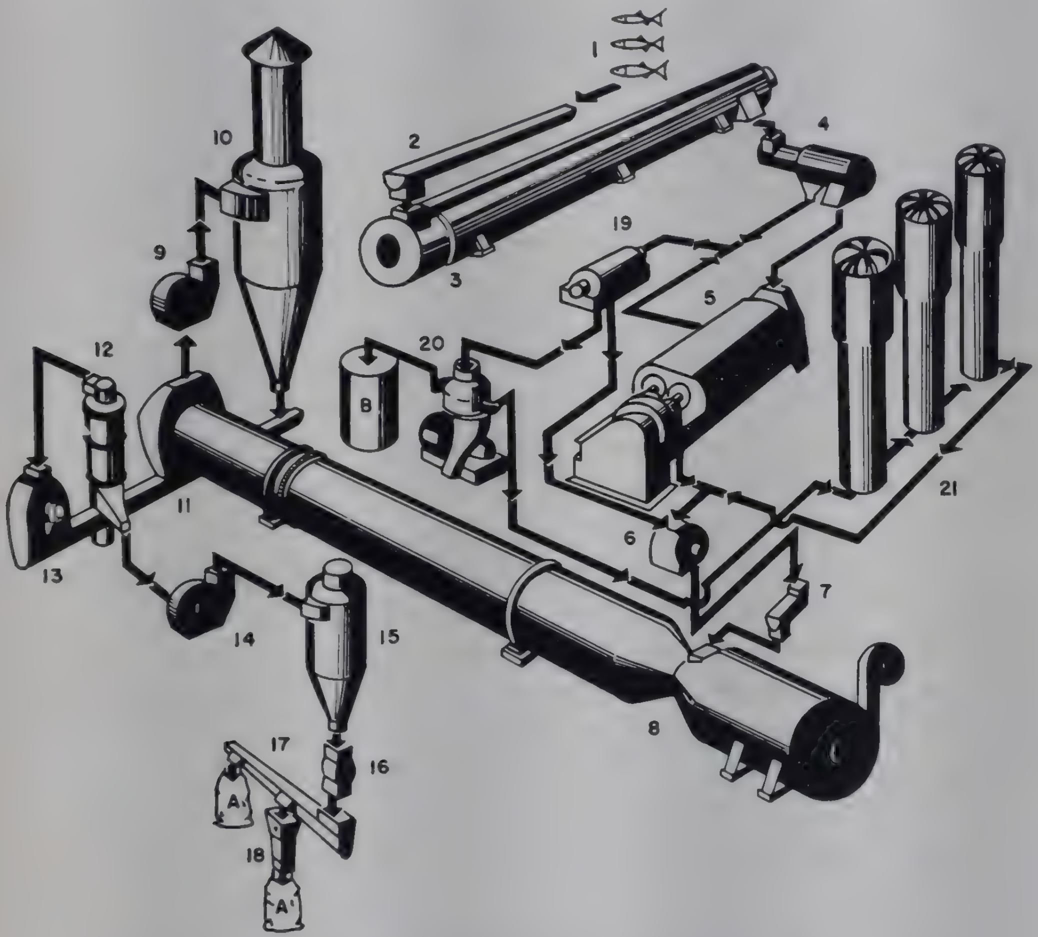

Fig. 1. Flow sheet for manufacture of fish meal and fish oil.

1. Fish storage
2. Screw conveyor
3. Cooker (indirect)
4. Rotating screen
5. Press (double screw)
6. Press-cake disintegrator
7. Mixing screw
8. Rotatory dryer
9. Pneumatic conveyor (fan)
10. Meal collecting cyclone
11. Meal conveyor
12. Vertical sifter
13. Hammer mill
14. Pneumatic conveyor
15. Bagging cyclone
16. Separating magnet
17. Distribution screw
18. Automatic weight
    A. Fish meal
19. Sludge separator
20. Oil centrifuge
    B. Fish oil
21. Glue-water concentrator

as little as 50% moisture with, say, 3–5% fat. Obviously the result of pressing directly determines the quality of the meal. The performance of the press must therefore be closely watched, and feeding of the raw material to the cooker and thus the total capacity of the installation must be governed by the press. The press liquid contains more or less sludge that has passed through the press openings. This interferes with proper oil separation, besides representing a considerable loss of meal. Most of it is therefore recovered on rotating or vibrating screens and, being very oily, it is often returned to the cooker. Preferably it is reheated and pressed in a separate sludge press and added directly to the dryer. Continuous sludge centrifuges have appeared on the market, and are now extensively used. These separate the sludge with low enough fat content so that it can be dried without further treatment.

The cake from the press is ground in a chopper in order to facilitate an even drying, and then enters the dryer. Externally heated dryers are now all but obsolete. Rotating dryers with steam-heated tubes are common. But in the modern fish meal factories working at high capacity —up to 1000–1500 tons of raw material per 24 hours—some form of direct flame dryer is generally used. The drying has so important a bearing on the quality of the finished product that it will be discussed later in somewhat more detail.

The dried material generally contains about 8–10% moisture. It is transported to the milling section, frequently by air blowing but screw conveyors, belts, etc. are also used. The ground meal is sacked and stored in a way that allows it to cool and avoid spontaneous heating.

In this old process the press liquor, after passing the sieves, goes to the oil separation plant. Previously a system of settling tanks was employed for this purpose. This is now obsolete, a better oil and higher yield being obtained by the use of continuous centrifugal separators. These modern devices are so constructed that the fine sludge, which would otherwise choke the centrifuges in a very short time, is eliminated, either continuously or intermittently. The glue-water resulting from this separation generally contains 0.5–1% oil and 5–7% nonfatty solids. This glue-water was formerly wasted; this was a very serious drawback of the original wet process.

C. "Whole Meal" Methods

1. *General*

The loss of solids in the glue-water, as was mentioned, may amount to 20% of the total amount present in the raw material. In other words, by recuperating this loss we should get 25 lb. fish meal from 100 lb. fresh fish, instead of 20 lb. Many attempts have been made to recover the solids from the glue-water. In Norway, as early as the first world war, the glue-water was evaporated and reincorporated into the press-cake during drying. But this practice was discontinued, since the price of such meal was reduced because of its large proportion of water-soluble protein. This fraction is very different from the fiber protein, and the erroneous conclusion was arrived at that this new "full meal" or "whole meal" was an inferior product.

It was not until the high content of water-soluble B vitamins in the glue-water was demonstrated that real interest was shown in the recovery of the glue-water solids. A new product called "fish solubles" came on the market in the United States. This was glue-water, concentrated to about 50% total solids content, often after acidification and refining to remove sludge and excess fat. In other parts of the world the manufacture of "whole meal" was again initiated. A product was obtained which retained all the water-soluble vitamins of the raw material. It also became evident that the water-soluble protein very efficiently balances the fiber protein of the meal. This will be discussed later.

2. *Whole Meal via Solubles*

The simplest way of accomplishing this 100% utilization of meal production would be to incorporate the concentrated fish solubles into the press-cake and, after thorough mixing, pass the whole through the dryer. This is then a modification of the old wet process. The evaporation involves heavy expenditure of steam. Every effort was therefore made to obtain the glue-water without undue dilution with condensed steam. This gave rise to the "indirect cooker," where the raw material is heated indirectly by allowing steam to condense in an outer jacket of the cooker. Then, in order to get sufficient heating surface without increasing cooker dimensions, the transporting screw was made hollow, also admitting steam. In fact, in a modern "indirect cooker" the heating surface due to the screw is larger than that of the jacket, possibly in the proportion 2:1. The technical problems connected with this construction, e.g., the elimination of the condensate from the screw, need not occupy us here. The "indirect cooker" is a sturdy and reliable construction and an important part of the whole meal installation. It is evident that all subsequent heating, e.g., of the glue-water before oil separation, must be done with indirect steam in coils or with the more modern heat exchangers, instead of by blowing steam into the liquid. It may be mentioned here that quite a different type of indirect cooker has lately been tried with great success. It is the "tubular" cooker, heated indirectly by means of fuel gases.

Concentration of the glue-water in multistage evaporators presents some difficulty. Problems of scale formation have not been entirely overcome, and for certain raw material can be very serious. It is now becoming customary to pass the concentrate through oil separators before incorporating it into the press-cake. Thus extra oil may be recovered, and the resulting whole meal has a lower fat content. In order to accomplish this oil separation, and also to get a concentrate that is not too viscous for blending, the concentration is seldom carried beyond 35% total solids. The concentrate when hot is then still fairly fluid and readily absorbed by the moist press-cake. The heavier concentrates have a tendency to form a coating on the outside of the particles. This will result in a more hygroscopic, sticky meal after drying. A concentrate that is more readily absorbed can also be obtained by carrying out the concentration at higher temperatures, under pressure. Such a procedure permits very considerable saving in fuel. As a matter of fact, the evaporation can be effected without extra expenditure of steam. Working with temperatures in the three stages of the multiple-effect evaporator of e.g., 160°, 150°, and 130°C., respectively, the steam leaving the third stage can be used for cooking the raw material. The greatest advantage of the method, however, is that the same large volumes of fresh water, in many places difficult to get, would no longer be needed. Due to the breakdown of the gelatinous protein in the glue-water, with formation of less viscous albumoses, a concentrate of up to 50% solid matter can easily be added to the press-cake. This represents a welcome relief for the dryers, the capacity of which is heavily taxed with the introduction of whole meal manufacture. Passage of the glue-water through the evaporator is so rapid that the valuable growth factors seem to be but little affected, with the exception of pantothenic acid. This point will be discussed later. Possible adoption of this process of pressure evaporation is, indeed, dependent on the effect it will be shown to have on meal quality. For instance, the darker color of such a "whole meal" is considered by many to be a disadvantage from the selling point of view.

3. *Recirculation Method*

Instead of concentrating the glue-water and then adding it to the press-cake, the opposite procedure may be adopted, namely, partially drying the press-cake and then adding the glue-water without previous concentration. Dry meal absorbs the liquid with great difficulty but, before the finishing stage when about 25–30% moisture remains in the press-cake, the absorption is effected very readily. The drying process must therefore be carried out in two stages, e.g., drying to 25–30% moisture in one dryer and adding the glue-water, and finishing the process in a second dryer. A number of modifications of the method exist. The finished meal is of excellent quality; but the fuel consumption is necessarily high, as the evaporation of large amounts of water is carried out in the dryer in one stage, thus not taking advantage of the economy of multiple-effect evaporation.

D. OTHER REDUCTION METHODS

By far the bulk of fish meal is manufactured according to one of the methods so far described. But the possible variations are legion. Thus in Europe a variety of compact equipment is built for marine installation. Many consist of quite novel types, cookers heated by means of fuel gases and consequently requiring no steam, compact disk presses instead of the ordinary horizontal screw presses, flash treatment dryers, etc. Detailed descriptions of such equipment, of course, cannot be given in this short chapter.

Fundamentally new reduction processes have recently been suggested; most have actually been tested in practice, but are probably being used on only a very limited scale. It is not unlikely, however, that the wet rendering methods will sooner or later be supplanted by more rational ones. This will of necessity be a slow evolution because of the truly amazing capacity of the modern wet rendering equipment, and also because of the enormous capital now invested. But in this general survey it will be of interest to consider some of the new principles that might in time replace the methods now in practice.

1. *Dry Rendering*

The dry rendering process is well known in the slaughterhouse industry. In the manufacture of fish meal, where limited amounts of raw material are available, it is generally employed in smaller units. To install dry rendering equipment for treatment of 1000 tons or more of raw material per day is hardly reasonable. The characteristic feature of this method is that the fish is dehydrated *before* pressing. The drying generally takes place under vacuum and therefore, due to the low temperature, a meal with excellent nutritive properties is obtained. The process on a reduced scale is essentially a batch operation, although it can be made semicontinuous, e.g., by alternately filling and discharging two dryers from one preheater. The dryer is a steam-jacketed cylinder that rotates or has a stirring device. The drying operation generally requires several hours, and must be stopped at a definite moisture content. Dried to less than 8% moisture, the fat cannot be pressed out properly. The pressing is mostly carried out in discontinuous hydraulic presses, working with a pressure of 30–40 atm. The fat content of the resulting press-cakes can then be as low as 10%, and the hard compact cakes, presenting but a small relative surface, are very resistant to rancidity and may be stored for a considerable period. The oil from such dry rendering is much darker than the wet rendered oil, having dissolved coloring matter during the dehydration process, but is often readily bleached and refined.

Big dry rendering plants can be made to work continuously, with regard to both the vacuum drying equipment and the high pressure expeller. But the operation nevertheless requires much manual labor and is therefore not considered economical for large capacities. The fuel consumption is also large, since all the water has to be evaporated in single-stage operations. An advantage of the method is that practically all sorts of raw material, fat and lean, fresh and decomposed, can be worked up with equal ease.

2. *Dehydration in Oil*

A modification of the above method, which has been tried out on both fish and marine mammals, consists in dehydrating the raw material in a bath of oil. In such equipment the contact with the heating surface is excellent, and it is kept clean and free of scorching material on account of the oil. The drying under vacuum takes place rapidly, and this part of the process has always been quite satisfactory. The pressing to obtain a pure oil and a fairly lean press-cake has met with less success. In any case the method has in this respect the same drawbacks as the straightforward dry rendering. It is felt that unless solvent extraction proves economically feasible in the fish meal industry, the latter methods will not prove successful.

3. *Solvent Extraction*

These processes are so well known, being carried out on a huge scale on many different raw materials, that they need not be described here in detail. Only a few facts relating to fish as raw material will be pointed out. A characteristic feature of the old extraction processes is that the stuff to be treated must be dried beforehand. That is, the starting material may be an already finished fish meal, produced by one of the methods described, wet or dry rendering. From this dry mass the oil is extracted by means of a liquid sufficiently volatile and a good fat solvent. The extraction can be carried out as a batch process or continuously, in both cases in countercurrent fashion, the fatty material being brought in its original state in contact with a miscella already containing dissolved fat; then, as the meal becomes exhausted, it gradually encounters the pure solvent. In a batch operation this means extracting the meal with a weak miscella and washing the once-extracted mass with pure solvent. The reason for this is of course to obtain the highest possible fat concentration in the miscella before distilling. This distillation to liberate the fat and to recover the solvent is a fuel-consuming operation, and frequent repetition entails considerable loss of solvent.

In practical operation the fat content of the extracted fish meal is around 1–2%. The meal then has a light color and should be fairly odorless. The smell of solvent should also have been carefully removed by blowing with dry steam. The meal is now less prone to rancidity, but after a time there frequently occurs a reversion of odor that may be objectionable. Another characteristic of extracted meal is its dustiness, which is sometimes overcome by adding less unsaturated neutral fat. The protein content of such meal is very high, generally in the neighborhood of 80%, and this sometimes makes it less convenient for use in feed mixes.

The color of the extracted oil is generally very dark, especially if chlorinated solvents, such as trichloroethylene or carbon tetrachloride, have been used. The price obtained for such an oil is therefore hardly sufficient to pay for extraction expenses. The better price commanded by the protein-rich meal is of course counteracted by the reduced tonnage resulting after the fat elimination.

Another difficulty very often met with in fish meal extraction is caused by the finely distributed solid particles—the “fines”—which can be eliminated only by costly operations.

As was stated, we believe that extraction of dried fish meal will not become a standard procedure in the fish meal industry for many years. The so-called wet extraction may be more advantageous. The principle underlying this method is the following.

4. *Wet Extraction*

The fish or offal, in its original wet state, is mixed with a fat solvent of fairly high boiling point, immiscible with water. The mixture is heated indirectly by means of steam. The water, together with part of the solvent, evaporates. The vapors condense and the two phases, water and solvent, separate. The solvent returns to the process. When the moisture content of the raw material has reached, say, 10% the dehydration is discontinued, the miscella drawn off, and the fat separated from the solvent by distillation.

The water in this process is removed by so-called azeotropic distillation. The mixed liquid solvent/water boils at a lower temperature than either of the two components, and the vapor will have a fixed composition. A solvent employed for azeotropic distillation in Europe is perchloroethylene. This forms with water an azeotropic mixture boiling at 87.7°C., the vapors containing about 84% by weight of perchloroethylene. According to an American patent, trichloroethylene is preferred. These chlorinated solvents have the advantage of being noninflammable, but extract much coloring matter from the raw material and are corrosive and poisonous, so that traces must be thoroughly expelled from the finished meal and oil.

The loss of solvent has been given as about 1% by weight of the raw material treated. The use of the cheaper hexane or other volatile hydrocarbons might therefore be preferred, were it not for the fire hazard. The fuel expense of azeotropic distillation is also high; not only is the moisture in the raw material driven off in single-stage evaporation, requiring more than 1 lb. steam per lb. water evaporated, but also substantial amounts of solvent are evaporated over and over again, and the latent heat of the vapors is lost.

Several small wet extraction installations are operating, mostly on fish livers, viscera, etc. It is doubtful, however, if the process can be adapted to full-scale fish meal manufacture.

It has been proposed to combine the process with the orthodox cooking/pressing process. In this case only the press-cake would be solvent-extracted. This would yield the bulk of the oil as prime quality oil and would greatly reduce cost of equipment and operation of the azeotropic distillation plant. It would require, however, extra cooker and press, besides apparatus for concentration of the press liquid. This operation carried out in a multistage evaporator would, on the other hand, be much more economical. Such a combined process has apparently not gone beyond the experimental stage.

We feel it should be sufficient to mention briefly a few further methods for fish meal manufacture, patented and conducted on a semicommercial or pilot plant scale. They include the following.

5. *Use of Supersonics*

Both German and British methods for such processes have been published. The "ultrasound" is generally produced by some sort of hammer mill. The vibrations employed seem to be about 10,000 per second, in other words not quite "supersonic." The vibration is transmitted to the liquid containing the fatty raw material. Part of the fat is then driven out, at a low temperature. The difficulties in recuperating the solid matter are considerable, except in the case of bones where the process seems to have met with some success.

6. *Solubilization Processes*

These methods do not produce fish meal, properly speaking, but semiliquid pastes, sometimes called "liquid fish." They seem to have been inspired by the success of "condensed fish solubles." Apparently lean fish or fish waste is intended to be used in these processes, but it should also be possible to use herring or other fatty fish by introducing a cooking and pressing operation.

One method consists in treating the fish at a high temperature (100–150°C.) with strong acid, e.g., sulfuric acid. Working at a pH as low as 3.0 or even lower, most of the fish is dissolved in the course of 3–4 hours. The liquid is then neutralized and condensed to a paste with, say, 50% total solids in multiple-effect evaporators.

The solubilization may also be effected through enzymes by adding commercial proteolytic ferments or employing those already present in the digestive tract of the fish. During the period when the fish are feeding, the gastric juices are very active and may liquefy the fish protein in less than 24 hours. The bones, however, remain and must be treated separately. As far as is known this principle has been tried only in pilot plant operation.

Digestion of the fish by means of alkali has been tried in Great Britain. While the yield and quality of the oil are found to be very good, the utilization of the protein matter has proved a difficult problem, due to the destructive action of the alkali. The process has therefore little hope of proving successful.

In connection with this short review of methods of fish meal manufacture, it might be expedient to mention one characteristic common to many of them: the amounts of malodorous gases emanating from the drying operation. All efforts to eliminate this smell, by washing with water, treatment with chemicals such as chlorine, ozone, etc., have proved unsuccessful. The only effective method so far proposed is to burn the gases with or without condensing the water vapor they contain. If the gases are exposed to temperatures above 500°C., the smell is completely eliminated. The remaining problem is then how to utilize the heat thus created so as not to spend an excessive amount of fuel oil.

V. Fish Meal Production: Statistics

Fish meal is a product now firmly established on the market, and produced in many parts of the world. Since prewar days the production has about quadrupled, and is apparently still increasing.

Table I has been compiled from data issued by the Food and Agriculture Organization, and will suffice to give a general impression of the importance of the industry.

TABLE I
FISH MEAL PRODUCTION
(1000 metric tons)

Area	1938	1948	1952/54[b]	1955/57[b]	1958/60[b]	1960	1961	1962	1963
Peru	na[a]	1.1	12.6	35.2	339.2	558.3	839.8	1,111.4	1,159.2
United States	185.6	195.5	297.5	355.9	339.5	351.1	382.3	393.8	208.3
Japan	190.3	34.3	98.2	142.8	261.6	312.7	362.2	390.9	na[a]
South Africa	3.5	10.7	95.9	89.4	124.2	148.0	189.1	214.0	238.3
Scandinavia	110.6	140.5	238.0	238.4	205.7	198.6	215.9	217.1	238.2
Soviet Union	na[a]	10.9	27.4	40.9	63.9	85.1	100.6	112.2	na[a]
Iceland	23.3	41.2	27.2	39.7	56.4	55.8	70.7	81.9	87.7
Chile	na[a]	0.8	7.8	15.1	30.2	42.3	58.0	91.6	90.4
United Kingdom	40.0	60.1	82.3	89.4	77.8	76.2	73.0	72.4	75.3
West Germany	73.6	16.6	67.5	79.8	83.7	82.9	68.4	81.4	74.0
Angola	0.1	14.2	41.1	71.8	55.3	44.8	55.3	33.0	87.7
Total	627.0	525.9	995.5	1,198.4	1,637.5	1,955.8	2,415.3	2,799.1	na[a]

[a] Figures not available.

[b] Average yearly production based on total for 3 years.

By far the bulk of the production consists of meal from the fatty fishes: herring, sardines, pilchard, maasbanker, menhaden. Small amounts of white fish meal, fish scrap from offal and from crustaceans and other aquatic animals, and "fish solubles" for the United States production, are also included.

Table I illustrates the meal production of Japan, Norway, Peru, United States, and other major producers. In this table, the amounts of "condensed fish solubles" are *not* included in the figures for the United States. The production of such concentrates has in latter years amounted to some 100,000 metric tons per year. The most interesting feature in this development is the spectacular change that has taken place in relative production by the leading manufacturing countries and the unique upsurge of Peru, only recently, followed by Chile.

The catch required for this massive fish meal production of Peru (1963) exceeds that of the entire Soviet Union, thus bringing this South American country to the position of second ranking nation in terms of landed fish, the overwhelming majority (96%) consisting of "anchoveta," converted into oil and fish meal by the reduction plants. American, European, and Japanese capital have strongly contributed to this Peruvian boom.

As indicated, Chile is entering a similar expansive development with a rapidly growing fish meal industry, also with foreign capital, some of which comes from the Union of South Africa. The figures for its fish meal output are expected to mount considerably, beginning with 1964.

Before the war, the United States and Japan competed for first place with yearly productions around 200,000 tons. The United States output has been fairly constant, showing a small regular increase and reaching 270,000 tons in 1961 after a peak of about 320,000 tons (exclusive of "solubles") in 1959.

Japan's production on the other hand dropped drastically after the war, but then steadily recuperated so that production today lies around 400,000 tons, second only to Peru. A major factor in this development has been the large scale floating processing units which are dispatched on long range expeditions to the Bering Sea and to African waters off Angola. Temporarily, these ships have also served off the coasts of Chile and Peru. (See also Chapter 12, p. 363, of this volume.)

The third classical fish meal producer, Norway, steadily increased its production during the postwar period to attain in 1954–56 first place, with some 250,000 tons per year. Then, due to failure of the herring fisheries, the tonnage suffered a serious decline.

Fish meal production in Africa before the war was practically nonexistent. The diagram shows how the output climbed, to about 100,000 tons in 1953, remaining fairly constant until very recently.

Finally, Table I shows the spectacular rise of the Peruvian fish meal industry from practically nil in 1953 to 1,159,200 tons in 1963.

VI. Properties of Fish Meal

A. GENERAL

The bulk of fish meal now produced is used in animal feeds. It usually finds its way to the big feed-mixing mills, but in many parts of Europe is still used on the individual farm. In some places it is shipped in the form of fish scrap, but is mostly put up in the form of ground meal. It should then be fairly uniform in particle size, free from bone splinters, fish eyes, and other coarse matter retained by an 8-mesh sieve. The fraction passing 50-mesh is still fairly great. Such meals, however, are not excessively dusty, on account of the fat. In extracted meals on the other hand with a fat content as low as 1–2%, the dust is often a nuisance.

The color of newly produced fish meal is mostly grayish green; with time, more rapidly after storage at high temperatures, it takes on a yellowish brown color apparently without detriment to its nutritive quality. The smell is characteristically "fishy," and in time becomes rancid.

It should be noted that much inferior fish meal and fish scrap do not correspond to this description.

The danger of fish meal as a carrier of *Salmonella* germs has received much attention lately, and it goes without saying that precautions must be taken to avoid this contamination. This is not difficult if the production is carried on uninterrupted from cooking to bagging, and no sweepings from dirty floors, etc. are added to the meal.

The commercial quality of fish meals is generally indicated in a "routine" analysis, giving the percentage of protein, fat, ash, and moisture. Conventional methods of analysis and calculation must be followed. The sum total of the above items is found to be close to 100%, indicating that the meal does not contain substantial quantities of other compounds, such as cellulose, sugars, etc. An exception to this is found in the case of fish liver meal.

The relative proportions of the four ingredients vary within wide limits, depending on the species of fish used, but much more important is the relative amount of fish bones in the raw material, the thoroughness with which the oily matter has been expelled, and the final moisture content of the meal. The composition of fish meals of different origin has been given by Creac'h (1950). However, it is not possible to set down norms for meals from various parts of the world. It must suffice to give here the following limits:

Moisture	6–10%
Fat	5–12%
Protein	60–75%
Ash	10–20%

A moisture content of less than 6% is rarely encountered since it is hygroscopic, an excessively dry meal would soon readjust its moisture content in accordance with the humidity of the atmosphere. The packing of meal in the fairly moistureproof polyethylene-coated bags will retard such a process. Meal with moisture higher than 12% is likely to get moldy, and will probably be rejected by the user.

It is difficult to produce from oily fish a meal with less than 5% fat. This would mean a press-cake with as little as 2.5–3% fat, which seems to be a practical limit. Extracted fish meal may show 1% fat or less, depending upon the exhaustiveness of the extraction. In general, the sooner after manufacture the meal is extracted, the easier the extraction becomes. On the other hand, meal from white lean fish may show 1% fat or less, even without cooking and pressing.

If the reduction process is carried out carelessly, when the raw material has not been completely coagulated and hence the pressing has been inefficient, it is not uncommon to get fish meals with 12–14% fat. Some raw materials are more difficult to handle than others. Newly caught fish generally tend to give a fatter meal. The same is true of partly decomposed raw material, which does not yield so firm and dry a press-cake. It should be mentioned in this connection that the apparent fat content of fish meal seems to decrease 2–4% during storage. This is due to the fact the the oxidized and partly polymerized fat is not so easily extracted with the solvents used in the analytical routine. The different solvents also behave differently in this respect.

The ash, that is the mineral matter, is derived mainly from the fish skeleton. The ash content is therefore especially high when fish heads and other offal is employed. The ash consists mainly of calcium phosphates; it is a valuable ingredient in the feed mixes, and meal with high ash and correspondingly lower protein content is in many cases preferred to the protein-richer meals. The mineral matter of the meal contains in many cases a high proportion of chlorides. This may come from the salt used for preservation purposes, or from chlorides used to improve coagulation of the cooked mass. This salt, while not detrimental, adds nothing to the commercial value of the meal. Sun-dried meals from primitive plants often contain sand, clay, and other foreign matter.

The protein content varies inversely with the other ingredients, being therefore especially high in dry low-fat meals. This explains the fact that some meals contain as much as 75% protein, while others contain less than 60%, perhaps nearer to 50%, if they have high ash and fat contents.

The valuable B vitamins and other growth factors contained in fish meal of course represent so small a quantity by weight that they do not modify its percentage composition. Nor are determinations of these compounds generally included in the routine analyses.

B. Protein

Fish meal is mainly a protein feed and must, therefore, be rightly valued as such, in the first place on the basis of its percentage of "crude protein"—i.e., percentage nitrogen multiplied by the conventional factor 6.25.

Such a valuation is, however, very incomplete. A first requirement is of course that this protein should be digestible. The determination of digestibility of fish meal, carried out *in vitro* by means of pepsin and hydrochloric acid, gives values generally considered to be in fair agreement with biological tests, and can be carried out with an insignificant expenditure of time and money compared with feeding tests on animals.

A good fish meal should show a protein digestibility of 92–95% (based on total protein content). Very rarely higher figures are found. On the other hand, meals manufactured from decomposed raw material or by faulty processing, such as overheating during the drying operation, spontaneous heating during storage, or storage for years—such meals will show a low digestibility. In extreme cases, less than 80% and even lower digestibilities may be found.

Often a distinction is made between "crude" (total) and "pure" protein. The latter is the nitrogenous matter precipitated by a certain alum-copper reagent, which leaves amides, meat bases, urea, etc. in solution. This latter fraction is especially abundant in the glue-water, where it may amount to 30% or more. "Whole meal" consequently also contains more "amides" than "ordinary" meal. Occasionally "pure digestible protein" is also indicated in analyses. As will be clear from the following considerations, an evaluation of the nutritive properties from such data is not justified. Often a determination of "water-soluble" protein or "water-soluble N" is carried out. This is an easy way of recognizing a "whole meal" in which in most cases the water-soluble N amounts to 18–20% of the total N, while for an "ordinary" meal 6–7% is customary. Of course all kinds of intermediary values may be found, depending upon the extent to which the glue-water solids have been recovered.

The real value of a protein feed is measured by its relative content of "essential" amino acids. Complete analyses of most of the commercially important proteins are now available, giving the composition of the amino acids with a high degree of accuracy. Such tables are no doubt given elsewhere in this volume and show how favorably fish protein compares with many other proteins with regard to amino acids. As further illustration, Table II (Boge, 1960) is given here, showing all the important amino acids in herring, in herring meal, and in the intermediary products press-cake, glue water, etc.

TABLE II

AMINO ACID COMPOSITION OF FISH AND FISH PRODUCTS

Amino acid[a]	Herring[b]	Press-cake	Glue-water	Meal	Whole meal
Arginine	7.14	8.15	5.38	8.10	7.86
Histidine	1.87	2.03	1.21	2.10	1.84
Isoleucine	6.20	6.75	1.98	6.70	6.12
Leucine	7.14	7.45	3.29	7.60	6.85
Lysine	8.34	9.05	4.57	9.06	8.18
Methionine	2.56	2.65	1.32	2.72	2.49
Phenylalanine	3.57	3.85	1.61	3.87	3.55
Threonine	4.1	4.07	2.24	4.19	4.0
Tryptophan	0.78	0.82	0.16	0.81	0.72
Valine	5.38	5.74	2.57	5.85	5.33
Tyrosine	3.0	3.27	0.72	3.30	2.89
Cystine	1.4	1.6	0.42	1.6	1.3
Glycine	6.31	5.4	10.2	5.66	6.28
Alanine	7.64	7.71	7.29	7.45	7.45
Aspartic acid	9.42	9.90	4.96	9.82	9.10
Glutamic acid	11.44	12.05	7.73	12.03	11.75
Proline	4.23	4.34	4.6	4.32	4.6
Serine	4.1	4.5	ca. 2.9	4.63	4.15

[a] Values given as % of crude protein (N × 6.25).

[b] Norwegian winter herring.

It should be noted that besides the 10 amino acids generally considered "essential"—the first 10 in Table II—a few of the others are also important in nutrition. The fairly high content of cystine, for instance, has a sparing effect on the essential methionine. The same thing applies to tyrosine with regard to phenylalanine, while for poultry the simple glycine—alpha-amino acetic acid—is of importance.

The difference between the protein in meal and in glue-water is most striking. In the glue-water, the content of all the amino acids—with the exception of glycine—has been reduced, in many cases to 50% or even less. The sum total of all the acids makes only some 65%, while for a pure protein this figure should be in the neighborhood of 110 (taking into account the water added during hydrolysis). This proves that much of the nitrogenous matter is not protein at all, being made up of a variety of "amides" and meat bases.

The protein of the glue-water may be exposed to destructive heat during concentration. When this is carried out at low temperatures the damage is negligible. In most multiple-effect evaporation the liquid will remain at temperatures above 100°C. for longer or shorter periods, depending upon the construction of the evaporator; if this is designed to work under pressure in all its stages, the high temperatures occasion serious losses of several of the amino acids. The acids that suffer most during high temperature evaporation are cystine, histidine, and tryptophan. They are the same acids that are sensitive to hard drying. It is astonishing though that the lysine, sensitive as it is to excessive drying, does not seem to suffer under this treatment.

The glue-water is lacking chiefly in tryptophan, cystine, isoleucine, and tyrosine. The protein is therefore highly "unbalanced" or incomplete. Laksesvela (1958) fed chicks on glue-water (or concentrated solubles) as the only source of protein, but the animals did not survive. They invariably died after 2–3 weeks whether the protein was fed at a high or low level.

This, however, by no means proves that the "whole meal," containing as it does a substantial portion of glue-water protein, is an inferior product. The contrary is often the case.

Compare the amino acid content of meal and whole meal with that of the raw material. It will be seen that the latter is practically identical with whole meal—as indeed it should be—while the "ordinary" meal and the press-cake from which it is derived have a somewhat different composition. It contains a slightly higher percentage of essential amino acids. On the other hand, the proper balance of the acids must have been altered and this is clearly reflected in the feeding tests.

In a series of experiments, where herring meal was the only source of protein, Laksesvela varied the proportion glue-water protein/fiber protein in the feed. Optimum feeding results were obtained with glue-water protein proportions of 15–45%. Beyond this latter figure the protein efficiency rapidly decreased, and with more than 60% glue-water protein the results were fatal.

Contrary to what might be expected, a proportion of glue-water even considerably higher than that in whole meal thus gives optimum results in chick feeding. It must be borne in mind, however, that in "practical" diets, of which other proteins besides fish meal form a substantial part, this need not always apply; the actual value can be ascertained only by means of feeding tests.

The protein of the raw material is profoundly altered during the reduction process. The cooking operation partly coagulates the water-soluble albumins and globulins, which are originally present in soluble form. On the other hand, soluble gelatin is formed from the collagenous tissue and from the bones. Some of this is doubtless broken down further to albumoses, etc. But the cooking should not cause major alteration in the amino acid balance. Its influence on the protein value has so far received little attention.

On the other hand, it has been definitely proved that the drying may influence the quality of the protein. The work of Deas and Tarr (1949) and Clandinin (1949) may be referred to as an example. Indirect drying by means of steam is considered to be a mild treatment for the press-cake, and meal thus dried is generally of excellent quality. However, the possibility of overheating the charge in contact with the hot steam tubes cannot be ruled out entirely and, on the other hand, meals dried in flame dryers are often of the very highest grade. If the drying is so carried out that moisture from the interior of the wet particles diffuses sufficiently rapidly towards the surface, this surface will remain moist in the hot parts of the dryer. The temperature of this surface then tends towards a condition of equilibrium, the so-called wet bulb temperature, which can be kept close to the adiabatic saturation temperature of the hot gas entering the dryer. If the temperature is thus kept down by the moisture, it is not difficult to keep the material at any moment below, say, 100°C.

Work carried out at the Norwegian Herring Meal Institute has shown that the *inlet* temperature of the gases in the flame dryer may be even as high as 500–600°C. (about 950–1100°F.) without damaging the meal, provided the *outlet* temperature is kept well below 100°C. (212°F.). This is confirmed by Clandinin (1949), who found no difference between meal dried in a very high vacuum (25 mm. mercury) and meal flame-dried at 85°C. A short passage through the dryer under these conditions is of no consequence, while high outlet temperature in an incorrectly conducted drying operation will give a meal with reduced digestibility and loss of amino acids. The amino acids most easily damaged are: lysine; cystine; tryptophan; and histidine.

The fact that the amount of an amino acid is found to remain constant after heat treatment does not necessarily mean that the acid in question is still available as a nutritional factor. In view of the importance of lysine and the ease with which it is altered, the amount of so-called "available lysine" was studied by Carpenter and Ellinger (1957). The drop in "available lysine" proves to be a good indicator of the damage done to a protein, for instance by excessive heating. But restoring the lysine to its original level by adding synthetic acid does not remedy the damage, unless other acids affected by the thermal treatment are also added.

The remarks made here on damage caused by severe drying also refer to spontaneous heating of the meal during storage, a phenomenon to be discussed later. In this case also the protein value of the meal is reduced by the destruction or immobilization of the 4 amino acids mentioned above.

Study of the distribution and availability of amino acids in herring proteins has contributed to our knowledge of protein utilization in general. Improper balance between the amino acids may very easily lead to a serious condition because of amino acid antagonisms, the resulting unhealthy state being not merely due to the shortage of an amino acid as building material. Moreover the antagonisms may be very complex, in addition to those of simpler type such as the well-known inhibitory action leucine may have upon isoleucine. The balance between the amino acids frequently appears to be more important than protein level (Laksesvela, 1961). The addition of even some of the "unessential" amino acids may be of advantage to the protein value of the feed.

The protein value of the meal is not constant indefinitely. For a period of a few years of proper storage no diminution of the nutritional value is observed. But gradually, even though the protein percentage (as measured by N × 6.25) is constant, the protein value is increasingly reduced; after 10–15 years the reduction may be very severe. The reason for this is not yet clear, but may have to do with an "immobilization" and consequently an altered balance of the amino acids.

C. Fat

The fat in fish meal is considered of little or no commercial value. The meal is evaluated on a protein basis, and the fat present reduces the protein percentage correspondingly. Liberal use of high-fat meal gives a "fishy" taste to the bacon or meat of animals fed on it. This drawback does not exist in careful feeding, with gradually diminishing amounts of meal.

The fat remaining in the press-cake is of the same highly unsaturated nature as the oil recovered during the pressing operation. Its exact composition may be somewhat different, with a higher free fatty acid value and more lecithin and cholesterol.

The fat in newly produced fish meal is already quite oxidized, and the fatty matter that can be extracted by organic solvents is more like a dark polymerization product. As the meal gets older this process continues. The fat incidentally gets more difficult to extract, and analysis of an old meal will therefore register a lower fat percentage than in fresh meal.

The oxidation is also accompanied by a darkening of the color of the meal, often giving rise to unevenness of color in the same lots. Even more important is the tendency of the meal to spontaneous heating during storage or shipment. This is directly traceable to the oxidation of the fat which gives off considerable heat of reaction. If the sacks are stacked so compactly that this heat cannot escape, the oxidation continues at an increasing rate and the whole mass may char, become red-hot, and perhaps even burst into flame. The complicated reactions with formation of peroxides, further oxidation, polymerization, and decomposition are still far from being completely understood, and need not be discussed here. The prevention of this self-heating is of course very important. By allowing the reaction to be carried to completion in the manufacturer's warehouse, with the temperature under control, the meal will have "matured" and should be safe. Many cases of incomplete "maturing" have, however, given rise to fires during transport or storage in the receiver's warehouse. Packing the meal in sacks practically impermeable to air is a measure in the opposite direction. The use of polyethylene-lined bags has given results so good that the danger of spontaneous heating has been overcome (Arnesen *et al.*, 1962). The oxidation has also been controlled recently by the addition of antioxidants. Meade in the United States (Meade, 1956) and later European workers have employed butylhydroxytoluene (BHT) for this purpose with great success. The addition of small amounts of BHT, about 0.02%, seems to prevent the spontaneous heating completely. The oxidation takes place at a rate so slow that the heat of reaction is given off to the surroundings without occasioning marked increase in temperature. Meal where the fat is stabilized with BHT keeps its original color for a considerable time. The smell is less rancid and, as might be expected, the fat seems to possess a higher nutritive value. On the other hand, no preservative action on labile amino acids, hence no improvement of the protein value after the addition of BHT, has been demonstrated.

Efforts to secure safe storage of fish meal without running the risk of spontaneous heating are continuing with a view to allowing the goods to be shipped in bulk. This is a more difficult proposition, although the same principles apply. The handling of fish meal in bulk, storage in silos, etc. would be of great economic advantage.

D. MINERALS

The mineral matter in fish meal consists mainly of calcium and phosphorus in the form of calcium phosphates. The meal may contain.

Calcium: 3.0–6.0% (CaO 4.0–8%)
Phosphorus: 1.5–3.0% (P_2O_5 3.5–7.0%)

This is an additional nutritive value of fish meal, since these elements form part of the animal skeleton. Fish meal plays in this respect a particularly important role, since it contains 10–15 times as much calcium and 4 times as much phosphorus as the most commonly used oil cakes. The meal manufacturer need not worry about these mineral components; the phosphates from the raw material are encountered in the meal regardless of the conditions of manufacture.

Apart from the phosphates—and possibly some chloride—the fish meal, like all other marine products, contains a number of "trace elements" or "oligoelements." They are present in infinitely small amount, but are nevertheless of the greatest importance for vital functions.

The order of magnitude of some of these elements is shown in the tabulation.

Elements	mg. per kilogram (approximate)
Zinc	70
Iodine	70
Iron	250
Copper	7
Manganese	4
Cobalt	0.04

The fish meal of the diet may therefore be of value in controlling an insufficient intake of minerals, even if the direct addition of minerals is to be recommended. As far as iodine is concerned, the amount present in fish meal is generally sufficient to take care of the requirement.

E. VITAMINS

Fish meal does not claim to be a particularly rich vitamin concentrate although we generally find that it contains a fair amount, especially of the B group factors. The fat-soluble vitamins are seldom present in significant amounts, the less so the more fully the oil has been eliminated during the reduction process. Vitamin A being very easily oxidized may be considered as virtually absent from the meal, while many types, especially those from fatty fishes may sometimes afford a certain supply of vitamin D.

Most fishes contain fair amounts of all the B vitamins. Thiamine is rarely very abundant in the usual raw material for meal manufacture, the vitamin being furthermore easily destroyed by enzymic action. The small amounts of folic acid are easily oxidized!

The factors that have been most carefully examined, especially in connection with herring meal manufacture, are riboflavin, pantothenic acid, niacin, and cobalmine (vitamin B_{12}). The variations in these components are not so marked that they need occupy us here. Apparently niacin fluctuates the most.

During storage of the fish in the bins no appreciable loss of vitamins occurs. Efforts to increase the riboflavin through fermentation have not been successful. During the cooking/pressing operation as a general rule about half the vitamins pass into the glue-water. The reduction process would therefore cause serious loss of vitamins unless the glue-water were reincorporated in the meal (or made into a separate condensate).

We should then expect whole meal to contain considerably more vitamins, and indeed we frequently find twice as much pantothenic acid and niacin in the whole meal. Riboflavin and B_{12} are not taken up to such an extent by the glue-water. In this case, when the vitamins are expressed in mg. per kg. of sample, the difference between ordinary meal and whole meal is not so striking. The following data from Boge (1956) illustrate this.

VITAMINS (in mg. per kg. of sample; average values)

Vitamin	Meal	Whole meal	Glue-water	Solubles[a]	Herring (winter)
Riboflavin	5.1	7.3	2.2	12.9	2.65
Pantothenic acid	15.2	30.6	10.0	54.5	10.4
Niacin	61.0	126.0	35.2	221	35.9
Vitamin B_{12}	0.21	0.25	0.074	0.36	0.1

[a] Calculated to 50% total solids.

The stability of the vitamins considered is quite good, with the exception of pantothenic acid. This latter frequently shows 50% loss or more under severe drying conditions. For the other vitamins, at outlet temperatures of less than 100°C. and with a reasonably good distribution of the material in the dryer, no serious loss of B vitamins need be feared. The shorter the drying period, the less the reduction.

As was the case with the amino acids, the B vitamins of the glue-water also undergo serious loss when the boiling temperatures are high and the processing time is long. Here too the pantothenic acid is the most sensitive vitamin.

The relation between vitamin B_{12} and the "animal protein factor" (APF) is far from clear. B_{12}, as has been observed, is remarkably resistant during the reduction process. This need not necessarily apply to the unidentified factor or factors.

VII. Utilization of Fish Meal

A. As Animal Feed

By far the greatest use for fish meal today is as an ingredient in animal feed mixes. Only the really inferior grades such as that produced by primitive means, sometimes dried in the open and put up as unground scrap often contaminated with sand and clay, are sold as fertilizer.

The good grades of fish meal are free from such contamination and free from insects, molds, and pathogenic germs. They constitute a valuable addition to the diet of our farm animals. Indeed, fish meal has come to be considered virtually indispensable for pigs and poultry.

The success of fish meal arises in the first place from the great nutritional value of its chief constituent, the protein. As was pointed out, fish meal is exceptionally well balanced as regards the amino acid distribution of its protein. This is of value even in the mixed feeds. Most vegetable feed does not provide sufficient methionine and/or cystine and/or lysine and is often lacking in tryptophan, even if the protein content is fairly high. It is evident that the richer a feed component is in essential amino acids, the greater is its value.

Because of the ability of ruminants to synthesize amino acids in the rumen by means of microorganisms, such animals are less dependent on the composition of the protein than are pigs and poultry. Nevertheless, cows with high milk production may well benefit by receiving additional important amino acids through the feed. Fish meal is normally used in feed mixed with vegetable cakes, where 10–40% of fish meal may be used. It is also particularly important that no serious decomposition of fish meal takes place through deamination in the alimentary canal of the ruminants, as is the case with much protein matter.

Fish meals may likewise be used for oxen and young animals, and for sheep and goats during stall feeding.

Fish meal is considered too expensive an article, however, to find extensive use in the feeding of ruminants, which it is felt could do without it from the point of view of both protein quality and vitamin content.

The real outlet for the meal is in the feeding of pigs and especially in the raising of poultry. Here the quality of the protein and the vitamin content is of greater importance. But more than any other single factor, the presence of the unidentified animal protein factor or factors has been investigated, although these compounds have not been determined quantitatively. Their presence is demonstrated beyond doubt through the growth stimulation in pigs and poultry. While this factor is doubtless present in varying amounts in different types of meal, and while the response to it is variable and dependent upon many external conditions, the following example from a Norwegian experiment (Laksesvela, 1954) is illustrative. In a continuous series of 13 trials carried out with a view to ascertaining the nature of the action of APF in herring meal upon chickens in the first 6 weeks of life, an addition of 7% herring meal resulted in weight increase of about 11% compared with the control receiving only vegetable protein in the feed.

A similar effect was shown by slaughter pigs. When ready for the slaughterhouse (90 kg. live weight), the growth was 5–12% greater in pigs that had received a supplement of herring meal than in control animals receiving vegetable food. These results were obtained with a total herring meal consumption of 5–10 kg. per animal, calculated on an average of 5 experiments. The rations in these cases were intended to be complete and of the same weight in respect to protein, vitamins, and mineral matter.

B. For Human Consumption

The transition from fertilizer fish scrap to high grade fish meal for feeding purposes was not a revolutionary one; it simply implied a steady improvement in quality. Thus it is not unlikely that fish meals, produced according to one of the "orthodox" methods may become a product fit for human consumption.

The lack of protein of high nutritional value is a most serious world problem, especially in the tropical countries, and for a long time the FAO (Food and Agriculture Organization) (Cutting and Bakken, 1957) has been engaged in a study of a solution. Through the United Nations Children's Fund, a series of large-scale tests have been conducted in a number of countries to assess the acceptability of such products. The tests comprised both nondeodorized and flavorless meals.

The first type simply consists of fish meal prepared from either whole fish or fish with most of the bones removed. It requires handling under improved hygienic conditions, standardization, and packaging assuring protection against humidity, oxidation, and insect attack. According to investigations such meals are acceptable in many parts of the world, a strong flavor being often preferred and incorporation of the meals in local traditional dishes being fairly easy. This, according to the FAO, does not mean that any fish meal intended for fodder will be accepted. Even where strongly flavored meals are favored, people will not tolerate off-flavor of a type unfamiliar to them. The production of edible fish meals suitable for the different markets may well present its initial difficulties.

The production of a deodorized "neutral" fish flour, that can be directly incorporated for instance into meal for bread making, is quite a different proposition. It must of necessity be a costly process, involving as it does some form of solvent extraction to remove the fat mainly responsible for the fishy odor and unavoidable rancidity. The difficulties encountered have been summed up by Cutting as follows:

To remove the last traces of fishy taste and odor, and to obtain a product in which these properties do not reappear after some time in storage.

To find methods where the processing does not result in reduced biological value of the protein.

To carry out industrial production on an economical basis.

Although these problems were tackled years ago, methods are still in an experimental stage. The most promising results to the writer's knowledge have been obtained by the Fishing Industries Research Institute, Cape Town, where a pilot plant with daily production of 1–2 tons of extracted meal was, at least until recently, in operation. This process was briefly as follows.

Crude maasbanker meal is given 5–7 extractions with a solvent mixture consisting of 9 parts 96% alcohol and 1 part ethyl acetate. The extractions are carried out with mechanical agitation at the boiling point of the solvent, about 80°C. After the final wash the solvent is stripped from the meal under vacuum.

The method is stated to be simple in operation, relatively inexpensive, and capable of industrial application to the cheapest available raw material.

The development of such a method required a considerable amount of research. The fishy odors and flavors had to be removed and the reversion of odor had to be prevented. The biological value of the protein must be left unimpaired. Practical difficulties also cropped up, such as removal of the fishy odors and flavors of the spent solvent before it could be re-used in subsequent batches.

In spite of the apparent success of this method, it is still a question whether extraction of the already dried meal will prove to be the most advantageous solution.

The drying process gives rise to odors and flavors that are most difficult to remove completely. The extraction of the wet press-cake might give more satisfactory results. In the case of the higher priced products, the more costly method of wet extraction, for instance through azeotropic distillation, might prove to be economically feasible.

Efforts have been made to mask the residual or reappearing odor with flavoring agents. An interesting development in this direction is partial enzymic digestion of the fish meal protein. The faint peptonized odor thus developed—not unlike that of meat extracts—may be satisfactory for many purposes, and perhaps does not require complete removal of the fat, especially if the original product is not strongly rancid.

The modern dehydration methods are a step in the direction of producing high grade products capable of being "reconstituted" with water, and thus resembling in texture and taste the original product. In applying this principle to fish, it is found advisable to work with cooked minced fish. Such a product could be reconstituted, and thus used in prepared dishes such as fish cakes, pies, etc. According to Cutting (1955), dehydrated fish was produced on a pilot plant scale in the United Kingdom during the war. Stored under nitrogen gas in hermetically sealed tins, it remained edible for 2 years under temperate conditions and for 6 months under tropical conditions.

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LIST OF COMMON FOOD FISHES

This list comprises the most important economic (commercial) species of the world's ocean and major fresh-water fishes.

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English	Latin
Alaska pollock	See pollock, Alaska
Albacore (Atlantic)	*Seriola lalandi* Valenciennes
Albacore (Pacific), syn. long-finned tuna	*Thunnus alalunga* Bonnaterre
Alewife (Europe), syn. Allis shad, shad, rock herring	*Clupea* (*Alosa*) *alosa* Linnaeus
Alewife (United States, Canada)	*Pomolobus pseudoharengus* (Wilson) and *P. aestivalis* (Mitchill)
Alfonsino	*Beryx splendens* Lowe
Amberfish (America)	See Atlantic albacore
American plaice, syn. long rough dab	*Hippoglossoides platessoides* (Fabricius)
Anchovy (Australia)	*Engraulis australis* White
Anchovy (Azov Sea)	*Engraulis encrasicholus maeoticus* Pus.
Anchovy (Black Sea), syn. "Chamsa" (Russian)	*Engraulis encrasicholus ponticus* (Linnaeus)
Anchovy (European)	*Engraulis pseudoharengus* (Wilson), syn. *Engraulis encrasicholus* Linnaeus
Anchovy (Japanese)	*Engraulis japonicus* (Houttuyn)
Anchovy (Indian)	*Anchoviella indica* (van Hasselt), syn. *Engraulis* (*Stolephorus*) *indicus* Bleeker
Anchovy (Malayan)	*Stolephorus* spp.
Anchovy, northern (East Pacific)	*Engraulis mordax* (Girard)
Angelfish (Europe)	See monkfish
Angelfish (United States)	*Pomocanthus* and *Holocanthus* spp.
Angler, syn. lesser weever, stingfish	*Trachinus vipera* Cuvier and Valenciennes
Angler (Japan)	*Lophius litulon* Jordan
Angler (Northwest Atlantic), syn. goosefish	*Lophius americanus* Cuvier and Valenciennes
Anglerfish (United Kingdom), syn. monkfish, fishing frog, or silver salmon	*Lophius piscatorius* Linnaeus
Arctic char	*Salvelinus alpinus* Linnaeus
Arctic cisco	*Coregonus autumnalis* Pallas

English	Latin
Arctic cod	See polar cod
Arctic flounder	See polar plaice
Arctic grayling	*Thymallus arcticus* Pallas
Argentine (Atlantic)	*Argentina silus* Ascanius
Argentine (Pacific)	*Argentina sialis* Gilbert
Arrow-toothed flounder, arrow-toothed halibut	*Atheresthes stomias* (Jordan and Gilbert)
Atherine	See smelt (sparling)
Atka mackerel	*Pleurogrammus azonus* Jordan and Metz, syn. *P. monopterygius* (Pallas)
Atlantic round herring	See herring (Caribbean)
Atlantic tuna	See blackfin tuna
Atlantic wolf-fish, syn. catfish	*Anarhichas lupus* Linnaeus
"Ayu" (Japanese)	*Plecoglossus altivelis* Temminck and Schlegel
Barbel	*Barbus barbus* (Linnaeus)
Barracouta (Australia)	*Thyrsites atun* (Euphrasen)
Barracuda, syn. sea pike	*Sphyraena* spp.
Barracuda (Japanese)	*Sphyraena picuda* Bloch and Schneider
Bass (Atlantic), syn. salmon bass	*Morone labrax* (Linnaeus), syn. *Labrax lupus*
Bass, common (Japan)	*Nipon spinosus* Cuvier
Bass, striped	*Roccus saxatilis* (Walbaum)
"Beluga" (Russia)	See sturgeon (Danube)
Bib, syn. pout, pouting	*Gadus luscus* Linnaeus
Bighead	*Aristichthys nobilis* (Richardson)
Bigmouth, syn. bufflalofish, winter carp	*Megastomatobus cyprinella* (Cuvier and Valenciennes)
Black cod	*Erilepis zonifer* Linnaeus
Black sea bass	See giant sea bass
Blanquillo	*Branchiostegus* spp.
Blenny	*Enedrias nebulosus* (Temminck and Schlegel)
Bluefin tuna, syn. blackfin tuna, tunny	*Thunnus thynnus* (Linnaeus)
Bluefish	*Pomatomus saltatrix* (Linnaeus)
Bluegill	*Lepomis macrochirus* Rafinesque, syn. *Helioperca incisor*
Blue ling	See ling, blue
Blue mackerel	See Pacific mackerel
Blue pike	See blue walleye
Blue walleye	*Stizostedion vitreum glaucum* (Hubbs)
Blue whiting	See poutassou
Bluet	See skate
Bonito (Atlantic)	*Sarda sarda* Bloch
Bonito (Australia)	*Sarda australis*
Bonito (California)	*Sarda lineolata* (Girard)

English	Latin
Bonito (Pacific)	*Sarda chilensis* (Cuvier and Valenciennes)
Bonito, ocean	See skipjack
Bonito, plain	*Orcynopsis unicolor* (St. Hilaire)
Bonito, striped, syn. Oriental bonito	*Sarda orientalis* (Temminck and Schlegel)
Bordered skate	See skate, owl
Bowfin	*Amia calva* Linnaeus
Bream, fresh-water	*Abramis brama* Linnaeus
Bream, Ray's	See pomfret
Bream, sea (West Atlantic)	*Lagodon rhomboides* (Linnaeus)
Bream, sea (East Atlantic)	See sea bream
Brill (North Sea)	*Rhombus laevis* (Rondelet), syn. *Scophthalmus rhombus* Linnaeus
Brill (Northwest Atlantic)	*Lophopsetta maculata* (Mitchill)
Brill (Pacific)	See petrale sole
Brill (Oceania)	*Colistium güntheri* (Hutton)
Brisling	See Scandinavian sardine
Brook trout	*Salvelinus fontinalis* (Mitchill)
Brown trout	*Salmo trutta* Linnaeus
Buffalofish	See bigmouth
Bullhead	See catfish (fresh-water)
Burbot, syn. "nalim" (Russia)	*Lota lota* (*lacustris*) (Walbaum)
Butt	See flounder (Europe)
Butterfish	*Poronotus triacanthus* (Peck)
Butter sole	*Isopsetta isolepis* (Lockington)
Cape salmon	See geelbek, may also be *Elops saurus* Linnaeus
Capefish	See horse mackerel
Capelin (Arctic)	*Mallotus catervarius* (Pennaut)
Capelin (Atlantic)	*Mallotus villosus* (Müller)
Capeline (Pacific)	*Mallotus socialis* (Pallas)
Carp, common	*Cyprinus carpio* Linnaeus
Carp, crucian, syn. German (or Prussian) carp	*Carassius carassius* (Linnaeus)
Caspian lamprey	*Caspiomyzon wagneri* Kessler
Caspian roach	*Rutilus rutilus caspicus* (Jakimov)
Caspian sturgeon	See "sevruga"
Catfish (fresh-water)	*Ictalurus* spp., syn. *Pilodictis olivaris* Rafinesque
Catfish, banded	See Atlantic wolf-fish
Chain pickerel	*Esox niger* LeSueur
Char (Arctic)	See Arctic char
Char (Great Lakes)	*Salvelinus* (*Cristivomer*) *namaycush* (Walbaum)
Cherry salmon	*Oncorhynchus masou* (Brevoort)
Chinook salmon	See king salmon
Chub (North America)	*Leucichthys* spp.
Chub (Columbia River)	See peamouth

English	Latin
Chub mackerel	See Pacific mackerel
Chum salmon	*Oncorhynchus keta* (Walbaum)
Cigarfish	See round scad
Cisco	*Coregonus* (*Leucichthys*) *artedi* (LeSueur)
Coalfish	*Pollachius* (*Gadus*) *virens* (Linnaeus)
Cod (Atlantic), codling	*Gadus callarias* (Linnaeus), syn. *Gadus morhua* Linnaeus
Cod (Korean)	See pollock (Alaska)
Cod (Pacific)	*Gadus* (*morhua*) *macrocephalus* Tilesius
Coho salmon	See salmon, silver
Coley	See coalfish
Conger eel (Northwest Atlantic)	*Conger oceanicus* (Mitchill)
Conger eel (North Atlantic)	*Conger conger* (Linnaeus)
Conger eel (Northwest Pacific)	*Astroconger myriaster* (Brevoort)
Corsair	See Rockfish, rosy (Northeast Pacific)
Crappie	*Pomoxis* spp.
Croaker (Atlantic)	*Micropogon undulatus* (Linnaeus)
Cusk	*Brosme brosme* (Müller)
Cutlass fish	See scabbard fish
Cutthroat trout (Northwest Atlantic)	*Salmo clarki* (Richardson)
Dab (Europe)	*Limanda limanda* (Linnaeus)
Dab, long rough	See American plaice
Dab (Atlantic), longhead	*Pleuronectes* (*Limanda*) *ferruginea* (Linnaeus)
Dab (Oceania)	*Rhombosolea plebeia* (Richardson)
Dab (West Pacific)	See yellowfin sole
Dace (Northwest Pacific)	*Tribolodon hakonensis hakonensis* (Günther)
Danube sturgeon	See beluga (Russia)
"Dara"	See Indian salmon
Dogfish (Atlantic and Pacific)	*Squalus acanthias* Linnaeus, syn. *Sq. suckleyi* (Girard)
Dogfish, greater spotted	*Scylliorhinus stellaris* Linnaeus
Dogfish, Japanese	*Squalus mitsukurii* Jordan and Fowler
Dogfish (South Africa)	*Scylliorhinus capensis* (Müller and Hente)
Dogfish, smooth (American)	*Mustelus canis* (Mitchill)
Dogfish, smooth (European)	*Mustelus mustelus* Linnaeus
Dogfish, smooth-hound	*Emissola antarctica* (Günther)
Dogfish, (fresh-water)	See bowfin
Dog salmon	See chum salmon
Dolly Varden	*Salvelinus malma* (Walbaum)
Dolphin, syn. dorado	*Coryphaena hippurus* Linnaeus
Dover slime sole, syn. Dover sole (Northeast Pacific)	*Microstomus pacificus* (Lockington)
Dover sole	See sole (European)

English	Latin
Drum (fresh-water)	*Aplodinotus grunniens* (Rafinesque)
Eel (North America)	*Anguilla rostrata* (LeSueur)
Eel (Australia)	*Anguilla aucklandii* Philippi
Eel (Europe)	*Anguilla anguilla* Linnaeus
Eel (Japan)	*Anguilla japonica* Temminck and Schlegel
Electric ray	*Torpedo* spp.
Elephant fish (Nile)	*Mormyrus oxyrhynchus*
English sole (Northeast Pacific)	*Parophyrys vetulus* (Girard)
Eulachon	*Thaleichthys pacificus* (Richardson)
Fiddle fish	See angelfish
Flake, syn. huss or rigg	Various dogfish
Flatfish, "hirame" (Japan)	See starry flounder
Flathead (Australia)	Species of *Platycephalus, Neoplatycephalus, Trudis,* and *Leviprora*
Flathead (Pacific)	*Platycephalus indicus* Linnaeus
Flathead sole	*Hippoglossoides classodon* Jordan and Gilbert
Flounder (Europe)	*Pleuronectes flesus* Linnaeus
Flounder (Oceania)	*Rhombosolea* spp.
Fluke	See flounder (Europe)
Flying fishes	*Cypselurus* species (several), *Prognichthys agoo* Temminck and Schlegel, and *Hirundichthys affinis* (Günther)
Forkbeard, greater	*Phycis* (*Urophycis*) *blennoides* (Brünnich)
Forked hake	See forkbeard, greater
Fresh-water drum	*Aplodinotus grunniens* (Rafinesque)
Frigate mackerel	*Auxis thazard* (Lacépède)
Furnard	See gurnard
Garfish (Atlantic)	See gar pike
Garfish, sea (Australia)	Species of *Heporhamphus, Arrhamphus,* and *Hemirhamphus*
Gar pike	*Belone belone* Linnaeus
Geelbek	*Atractoscion aequidens* Cuvier
"Ghol"	See jewfish (India)
Giant sea bass	*Stereolepis gigas* Ayres
Gilthead	*Chrysophris auratus* (Bloch and Schneider)
Gizzard shad	*Dorosoma cepedianum* (LeSueur)
Globefish	*Sphaeroides* spp.; see also puffers
Grass carp	*Ctenopharyngodon idella* (Cuvier and Valenciennes)
Goldfish	*Carassius auratus* Linnaeus
Goosefish	See angler (Northwest Atlantic)
Gray cod	See cod (Pacific)
Gray mullet	See mullet, gray

English	Latin
Gray skate	See skate
Grayling (fresh-water) (North America and Europe), syn. Arctic grayling	*Thymallus arcticus* (Pallas) and *Thymallus thymallus* (Linnaeus)
Great blue shark	*Prionace glauca* (Linnaeus)
Great weever	*Trachinus draco* Linnaeus
Greenfish	*Girella punctata*
Greenland cod	*Gadus ogac* Richardson
Greenland halibut	*Reinhardtius hippoglossoides* (Walbaum)
Greenland shark	*Somniosus microcephalus* (Bloch and Schneider)
Grenadier	See rattail
Grouper (Oceania), syn. "hapuku" (Australia)	*Polyprion oxygeneios* (Bloch and Schneider)
Grouper (Atlantic)	*Epinephelus* spp.
Guppy	*Girardinus guppyi*
Gurnard	*Trigla* spp.
Gurnard (South Africa)	*Trigla capensis* Cuvier
Gurnard, red (Japan)	*Chelidonichthys* (*Trigla*) *kumu* (Lesson and Garnot)
Gwyniad	See powan
Haddock (Atlantic)	*Melanogrammus* (*Gadus*) *aeglefinus* Linnaeus
Hairtail (Atlantic)	*Scabbard fish* (Northwest Atlantic)
Hairtail (Japan)	*Trichiurus japonicus*
Hake (Atlantic)	*Merluccius merluccius* Linnaeus
Hake (Oceania)	*Merluccius gayi*
Hake (Pacific)	*Merluccius productus* Ayres
Hake (South Africa)	See stockfish
Halfbeak (Japanese)	*Hemiramphus sajori* Temminck and Schlegel
Halibut (Atlantic)	*Hippoglossus hippoglossus* (Linnaeus) syn. *H. vulgaris*
Halibut (Pacific)	*Hippoglossus stenolepis* (Schmidt)
Hammerhead (shark)	*Sphyrna zygaena* (Linnaeus)
Herring (Atlantic)	*Clupea harengus harengus* Linnaeus
Herring (Pacific)	*Clupea harengus pallasii* (Cuvier and Valenciennes)
Herring (Oceania)	*Aldrichetta forsteri* Cuvier and Valenciennes
Horse mackerel (Japan)	*Trachurus japonicus* (Temminck and Schlegel)
Horse mackerel (California)	*Trachurus symmetricus* (Ayres)
Horse mackerel (Oceania)	See scad (Australia)
Hottentot	*Pachymetopon blochii* (Valenciennes)
Huchen (Danube)	*Salmo* (*Hucho*) *hucho* (Linnaeus)
Humpback salmon	See pink salmon
Inconnu	*Stenodus leucichthys* Güldenstadt
Indian mackerel	*Rastrelliger kanagurta* (Cuvier)

English	Latin
Indian salmon, syn. "dara" or "kuru"	*Polydactylus* (*Polynemus*) *indicus* Shaw
Jack mackerel	*Trachurus trachurus* (Linnaeus)
Jack mackerel (Atlantic)	*Caranx hippos* (Linnaeus)
Jack mackerel (Indian Ocean)	*Caranx sexfasciatus* Quoy and Gaimard
Jack mackerel (Japan)	See horse mackerel (Japan)
Jacopever (South Atlantic)	*Sebastichthys capensis* (Gmelin)
Japanese mackerel	See Pacific mackerel
Japanese salmon	See salmon, cherry
Japanese sea perch	*Lateolabrax japonicus* (Cuvier)
Japanese sole	*Glyptocephalus stelleri* (Schmidt)
Japanese tuna	*Thunnus thynnus orientalis* (Temminck and Schlegel)
Jewfish (India), syn. "ghol"	*Johnius* (*Sciaena*) *sina* (Cuvier)
John Dory (United Kingdom, South Africa)	*Zeus faber* Linnaeus, syn. *Z. Capensis* Cuvier
John Dory (Australia)	*Zeus australis* Richardson
John Dory (Japan)	*Zeus japonicus* Valenciennes
Kabeljou	*Johnius hololepidotus* Lacépède
"Kalankan" (Indonesia)	See turbot (Indo-Pacific)
Kamchatka salmon	*Salmo mykiss* Walbaum
"Killifish" (Japan)	*Oryzias latipes* (Temminck and Schlegel)
King mackerel	*Scomberomorus regalis* (Bloch) and *Sierra cavalla* Cuvier
King salmon	*Oncorhynchus tschawytscha* (Walbaum)
Kingfish (Australian)	See Albacore (Atlantic)
Kingfish (Indian Ocean)	*Caranx* spp.
Kingklip	*Genypterus capensis* Smith
Ladyfish	*Elops saurus* Linnaeus
Lake herring (Lake Michigan)	*Coregonus clupea formis* (Mitchill)
Lake herring (Great Lakes, excluding Lake Michigan)	*Coregonus Leucichthys artedii* LeSueur
Lake sturgeon (United States)	*Acipenser fulvescens* Rafinesque
Lamprey (Atlantic and Great Lakes)	*Petromyzon marinus* Linnaeus
Lamprey (Caspian)	*Caspiomyzon wagneri* Kessler
Lamprey (Northeast Asia)	*Lampetra japonica* (Martens)
Lamprey, river	*Lampetra fluviatilis* and *L. ayresi* (Günther)
Lance	See sand eel
Lancetfish	*Alepisaurus ferox* Lowe
Lantern fish	*Diaphus coeruleus* Klunzinger
Lascar	See sand sole (Europe)
Leather fish, syn. tub, yellow gurnard	*Monacanthus cirrhifer*, syn. *Trigla hirundo* Linnaeus

English	Latin
Lemon sole (Northeast Atlantic)	*Microstomus (Pleuronectes) microcephalus* (Donovan)
Lemon sole (Oceania)	*Peltotretis flavilatus* Waite
Ling	*Molva* spp.
Ling, common	*Molva molva* (Linnaeus)
Ling, blue	*Molva dipterygia* (Pennant)
Ling (Mediterranean)	*Molva elongata* Risso
Ling (Oceania)	*Genypterus blacodes* Bloch and Schneider and *G. microstomus* Regan
Ling (Canada) (fresh-water)	*Lota maculosa* (LeSueur)
Lingcod	*Ophiodon elongatus* Girard
Little skate	See skate, little
Little tuna (Pacific, Indian Oceans)	*Euthynnus affinis* (Cantor)
Little tuna (Atlantic, Mediterranean)	*Euthynnus alletteratus* (Rafinesque)
Lizardfish	*Chlorophthalmus albatrossis* Jordan and Starks
Loach (minnow)	*Tiaroga cobitis* Girard
Longhorn sculpin	*Myoxocephalus octodecemspinosus* (Mitchill)
Longnose	See lancetfish
Long-nosed skate	See skate, long-nosed
Lumpfish	See lumpsucker
Lumpsucker	*Cyclopterus lumpus* Linnaeus
Maasbanker	South African name for horse mackerel
Mackerel (Atlantic)	*Scomber scombrus* Linnaeus
Mackerel (Oceania)	*Trachurus declivis*
Mackerel (Pacific)	See Pacific mackerel
Mackerel, Atka	*Pleurogrammus azonus* Jordan and Metz, syn. *P. monopterygius* (Pallas)
Mackerel shark	See porbeagle
Mackerel, Spanish	*Scomber maculatus* (Mitchill)
"Magur" (India)	*Clarias batrachus* Bleeker
"Mandeli" (India)	*Coilia dussumieri* Cuvier and Valenciennes
Man-eater	*Carcharodon carcharias* (Linnaeus)
Marlin	See spearfish
Marlin, black or blue	*Makaira nigricans* Lacépède
Marlin, striped	*Makaira audax* (Philippi)
Marlin, white	*Makaira albida* (Poey)
Megrim	*Lepidorhombus whiff-iagonis* (Walbaum)
Menhaden, Atlantic	*Brevoortia tyrannus* (Latrobe)
Menhaden, Gulf, syn. large-scale menhaden	*Brevoortia patronus* Goode
Mexican platyfish	*Platypoecilus maculatus*
Milkfish	*Chanos* spp.
Minnow	*Phoxinus phoxinus* (Linnaeus)

English	Latin
Mock halibut	See Greenland halibut
Monkfish (Northeast Atlantic), syn. anglerfish	*Lophius piscatorius* Linnaeus
Monkfish (Northwest Atlantic), syn. angelfish	*Squatina squatina* (Linnaeus)
Moonfish (Atlantic)	*Vomer setapinnis* (Mitchill)
Moonfish (Pacific)	*Vomer declivifrons* Meek and Hildebrand
Morgan (India)	*Cirrhina orius mrigala* Hamilton Buchanan
Mud carp	*Cirrhina miitorella* (Cuvier and Valenciennes)
"Muksun" (Russia)	*Coregonus muksun* (Pallas)
Mullet	*Mugil* spp.
Mullet, red (Northeast Atlantic)	*Mullus barbatus* Linnaeus
Mullet, red (West Atlantic)	*Mullus auratus* Jordan and Gilbert
"Muroaji" (Japan)	*Decapterus muroadsi* (Temminck and Schlegel)
Muskellunge	*Esox masquinongy* Mitchill
"Nalim" (Russia)	See burbot
"Navaga" (Russia) (Europe)	*Eleginus navaga* (Pallas)
"Navaga" (Russia) (Northwest Pacific)	*Eleginus gracilis* (Tilesius)
"Nelma" (Russia)	*Stenodus leucichthys nelma* (Pallas)
"Nigisu" (Japan)	*Glossanodon* (*Argentina*) *semifasciatus* (Kishinouye)
Norway haddock	See ocean perch
Nurse	See large or small spotted dogfish
Oceanic bonito	See skipjack
Ocean perch (Northeast Atlantic)	*Sebastes marinus* (*marinus*) (Linnaeus)
Ocean perch (Northwest Atlantic)	*Sebastes mentella* (*marinus*) (Travin)
Ocean pout	*Macrozoarces americanus* (Bloch and Schneider)
Oil sardine (India)	*Sardinella longiceps* Valenciennes
"Omul" (Russia)	*Corcyomus autumnalis* Pallas
Opah	*Lampris regius* (Bonnaterre)
Opaleye	*Girella nigricans* (Ayres)
Owl skate	See skate, owl
Pacific cod	*Gadus* (*morhua*) *macrocephalus* Tilesius
Pacific mackerel	*Scomber japonicus* Houttuyn
"Pala" (India)	*Macrura ilisha* (Buchanan Hamilton)
Pampano, common	*Trachinotus carolinus* (Linnaeus)
Pampano (Indo-Pacific)	*Trachinotus blochii* (Lacépède)
Parrot-fish	*Leptoscarus* spp.
Peamouth	*Mylocheilus caurinus* (Richardson)

English	Latin
Pechora herring	*Clupea harengus suworowi* Rafinesque
Pejerrey (Argentina)	*Odonthestes (Basilichthys) bonariensis*
"Pelyad" (Russia)	*Coregonus peled* (Gmelin)
"Peperek" (Indonesia)	See slimy
Perch (Europe, Asia)	*Perca fluviatilis* Linnaeus
Perch (North America)	*Perca flavescens* (Mitchill)
Perch (Japan)	*Lateolabrax japonicus* (Cuvier)
Perch, giant (Australia)	*Lates calcarifer* (Bloch)
Perch, ocean	See redfish
Peto	*Acanthocybium solandri* (Cuvier and Valenciennes)
Petrale sole	*Eopsetta jordani* (Lockington)
Piked dogfish	See dogfish (Atlantic and Pacific)
Pike (northern)	*Esox lucius* Linnaeus
Pike perch (North America)	See walleye
Pike perch (European, also in Caspian)	*Lucioperca lucioperca* (Linnaeus)
Pilchard sardine (W. Europe)	*Clupea (Sardina) pilchardus pilchardus* (Walbaum)
Pilchard (Mediterranean)	*Sardina pilchardus sardina* Walbaum
Pilchard (Japan)	*Sardina melanosticta* (Schlegel)
Pilchard (Northeast Pacific)	*Sardinops (Sardina) caerulea* Girard
Pilchard (Southwest Pacific)	*Sardinops sagax sagax* (Jenyns)
Pilchard (West Africa)	*Sardinella aurita* Cuvier and Valenciennes
Pilchard (South Africa)	*Sardinops ocellata* (Pappe)
Pilchard (Oceania)*	*Sardinella neopilchardus* (Steinacher)
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Pintado	*Scomberomorus regalis* (Bloch)
Piranha (Amazon)	*Serrasalmus (Rooseveltiella) nattereri* (Kner)
Pirarucu (Amazon)	*Arapaima gigas* Cuvier
Plaice (Northeast Atlantic)	*Pleuronectes platessa* Linnaeus
Plaice (North America)	See American plaice
Polar cod	*Boreogadus saida* (Lepechin)
Polar plaice	*Liopsetta glacialis* (Pallas)
Pole dab	See witch flounder
Pollock (Europe)	*Pollachius pollachius* (Linnaeus)
Pollock (Alaska)	*Theragra chalcogramma* (Pallas)
Pomfret (United States)	*Brama raii* (Bloch)
Pomfret, black	*Stromateus niger* Bloch
Pomfret, white	*Stromateus cinereus* Bloch
Poor cod	*Gadus minutus* Linnaeus
Pope, syn. ruffe	*Acerina cernua* (Linnaeus)
Porbeagle	*Lamna nasus* (Bonnaterre)
Porgy	*Pagrosomus* spp., *Stenotomus* spp., and *Calamus* spp.

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* In smaller sizes most of these pilchards are generally called sardines.

English	Latin
Pout	See bib
Poutassou	*Gadus* (*Micromesistius*) *poutassou* (Risso)
Pouting	See bib
Powan	*Coregonus lavaretus* (Linnaeus)
Puff-fish	See puffers
Puffers	*Sphaeroides* spp.; see also globefish
Rabbitfish	*Chimaera monstrosa* Linnaeus
Rainbow trout (North America)	*Salmo gairdneri* (*irideus*) (Richardson)
Rattail	*Macrourus* spp.
Rays:	*Raja* spp.; see also skates
Shagreen	*R. fullonica* Linnaeus
Thornbock, roughback	*R. clavata* Linnaeus
Spotted, homelyn	*R. montagui* Fowler
Blonde	*R. brachyura* Lafont
Starry	*R. radiata* Donovan
Sandy	*R. circularis* Couch
Painted	*R. microcellata* Montagu
Cuckoo	*R. naevus* Müller and Henle
Undulate, marbled	*R. undulata* Lacépède
Razorbelly	See scaled sardine
Red-eye	See rudd
Red bream (Northeast Atlantic)	See sea bream, common
Red goatfish	See red mullet (Florida)
Red mullet (Florida)	*Mullus auratus* Jordan and Gilbert
Red mullet (Europe)	*Mullus barbatus* (Linnaeus)
(Red) rowan	*Chrysoblephus laticeps* (Cuvier)
Red snapper	*Lutjanus blackfordi* Goode and Bean
Red steenbras	*Dentex* (*Petrus*) *rupestris* (Valenciennes)
Red stumpnose (South Africa)	*Chrysoblephus gibbiceps* Cuvier
Redfish (East Atlantic)	See ocean perch (Northeast Atlantic)
Redfish (West Atlantic)	See ocean perch (Northwest Atlantic)
River lamprey (Europe)	See lamprey, river
River lamprey (Japan)	See lamprey (Northeast Asia)
Roach (Europe)	*Leuciscus* (*Rutilus*) *rutilus* (Linnaeus)
Rock bass	*Ambloplites rupestris* (Rafinesque)
Rockfish, blue (Northeast Pacific)	*Sebastosomus mystinus* (Jordan and Gilbert)
Rockfish, brown (China)	*Sebastodes inermis*
Rockfish (Europe)	See catfish and wolffish
Rockfish (Japan)	*Sebastiscus marmoratus* (Cuvier)
Rockfish, rosy (Northeast Pacific)	*Sebastomus rosaceus* Girard
Rockfish (Northwest Pacific)	*Sebastodes flammeus*

English	Latin
Rock sole	*Lepidopsetta bilineata* (Ayres)
Rock salmon	See dogfish
"Rohu" (India)	*Labeo rohita* Buchanan Hamilton
Roker	See ray
Roughback	See dab, long rough
Round herring (Caribbean)	*Etrumeus sadina* (Mitchill)
Round scad	*Decapterus punctatus* (Agassiz)
Rudd	*Scardinius erythrophthalmus* (Linnaeus)
Russian sturgeon	*Acipenser güldenstädti* Brandt
Sablefish	*Anoplopoma fimbria* (Pallas)
Saffron cod	*Eleginus gracilis* (Tilesius)
Sailfin	See sandfish (Japan)
Sailfish	*Istiophorus* spp.
Sailfluke	See megrim
Saithe	See coalfish
Salmon (Atlantic); see also huchen	*Salmo salar* Linnaeus
Salmon (Australia)	*Arripis trutta* Bloch and Schneider
Salmon (Pacific), syn. Chum salmon or dog salmon	*Oncorhynchus keta* (Walbaum)
Salmon (Pacific), syn. sockeye (red)	*Oncorhynchus nerka* (Walbaum)
Salmon, cherry	*Oncorhynchus masou* (Brevoort)
Salmon, king or chinook	*Oncorhynchus tschawytscha* (Walbaum)
Salmon, pink, syn. humpback salmon	*Oncorhynchus gorbuscha* (Walbaum)
Salmon, sebago	*Salmo sebago* Girard
Salmon, silver, syn. Coho salmon or silversides	*Oncorhynchus kisutch* (Walbaum)
Salmon bass (Australia)	See kabeljou
Salmon bass (Atlantic)	See bass (Atlantic)
Salmon shark	*Lamna nasus* (Bonnaterre)
Sand eel	See sand launce (Northeast Atlantic)
Sandfish (Japan)	*Arctoscopus japonicus* (Steindachner)
Sand launce (Northeast Atlantic)	*Ammodytes* spp. and *Gymnammodytes* spp.
Sand sole (flounder) (Pacific)	*Psettichthys melanostictus* Girard
Sand sole (Europe)	*Solea lascaris* (Risso)
Sardine (Northeast Altantic)	*Clupea* (*Sardina*) *pilchardus pilchardus* (Walbaum)
Sardine (Australia)	*Sardina* (*Sardinops*) *neopilchardus* (Steinacher)
Sardine (Northeast Pacific)	*Sardinops* (*Sardina*) *caerulea* Girard
Sardine (Southwest Pacific)	*Sardinops sagax sagax* (Jenyns) (by some ichthyologists considered identical to the North Pacific species)

English	Latin
Sardine (Maine)	*Clupea harengus* Linnaeus
Sardine (India)	*Sardinella fimbriata* (Valenciennes)
Sardine (Northwest Pacific)	*Sardina* (*Sardinops*) *melanosticta* (Temminck and Schlegel)
Sardine (Scandinavia), syn. brisling	*Clupea sprattus* (Linnaeus)
Sardine (South Africa)	*Sardina ocellata* Jenyns
Sauger	*Stizostedion canadens* (Smith)
Saurel	See horse mackerel (Atlantic)
Saury (Pacific)	*Cololabis saira* (Brevoort) and *C. brevirostris* (Peters)
Saury pike (Atlantic), syn. skipper	*Scomberesox saurus* (Walbaum)
Scabbardfish (Northeast Atlantic)	*Lepidopus caudatus* (Euphrasen)
Scabbardfish (Northwest Atlantic)	*Trichiurus lepturus* Linnaeus
Scad (Northeast Atlantic)	See jack mackerel
Scad (Australian), syn. horse mackerel (Oceania)	*Trachurus novae-zelandiae* Richardson
Scaldfish	*Arnoglossus laterna* (Walbaum)
Scaled sardine	*Harengula pensacolae* Goode and Bean
Scup	*Stenotomus versicolor* (Mitchill)
Sea bass (Japan)	*Lateolabrax japonicus* (Cuvier)
Sea bass, white (California)	*Atractoscion nobilis* (Ayres)
Sea bream (Northwest Atlantic)	*Brama* spp. and *Taractes princeps* (Johnson)
Sea bream, common	*Pagellus centrodontus* (de la Roche)
Sea bream	Various species of the family Sparidae (including red bream above)
Sea lamprey	See lamprey
Sea perch, syn. white perch	*Morone americanus* (Gmelin)
Sea pike (Australia)	See snook (Australia)
Sea raven	*Hemitripterus americanus* (Gmelin)
Sea robin	*Prionotus* spp. and *Peristedion* spp.
Sea trout	*Salmo trutta trutta* Linnaeus
Sebago salmon	*Salmo sebago* Girard
"Sevruga" (Russia)	*Acipenser stellatus* Pallas
Shad (American)	*Alosa sapidissima* Wilson
Shad, Allis	See alewife
Shad, gizzard	*Dorosoma cepedianum* (LeSueur)
Shad, Twaite	*Clupea finta* (Cuvier)
Shark, basking	*Cetorhinus maximus* (Gunnerus)
Shark, great blue	*Prionace glauca* (Linnaeus)
Shark, Greenland	*Somniosus microcephalus* (Bloch and Schneider)
Shark, hammerhead (smooth)	*Sphyrna zygaena* Linnaeus

English	Latin
Shark, salmon	*Lamna nasus* (Bonnaterre)
Shark, silver	*Chimaera monstrosa* Linnaeus
Shark, soupfin	*Galeorhinus zyopterus* (Jordan and Gilbert)
Shark, tiger	*Galeocerdo cuvieri* (Peron and LeSueur)
Shark, white	See man-eater
Sharp-nosed skate	See skate, sharp-nosed
Sheatfish	*Siluris glanis* (Linnaeus)
Sheepshead (marine)	*Archosargus probatocephalus* (Walbaum)
"Shirada" (India)	*Wallago attu* Bleeker
Shovelnose sturgeon	*Scaphirhynchus platorhynchus* Rafinesque
Siberian cisco	*Coregonus sardinella* Valenciennes
Sierra	See King mackerel
Silverbelly (India)	*Leiognathus* (*Equula*) *bindus* Cuvier and Valenciennes
Silver carp	*Hypothalmichthys molitrix* Valenciennes
Silver salmon	*Oncorhynchus kisutch* (Walbaum)
Silversides	See salmon, silver
Silver hake	See whiting (Northwest Atlantic)
Silver perch	See drum (fresh-water)
Silver salmon	See salmon, silver
Skates:	*Raja* spp.; see also rays
Skate	*R. batis* Linnaeus
Little	*R. erinacea* Mitchill
Long-nosed	*R. oxyrhynchus* Linnaeus
Owl	*R. marginata* Lacépède
Sharp-nosed	*R. lintea* Fries
Skipjack	*Euthynnus* (*Katsuwonus*) *pelamis* (Linnaeus)
Skipper	See saury pike
Slimy	*Leiognathus equula* Forskal
Small-mouth buffalo	*Ictiobus bubalus* Rafinesque
Smelt (Europe)	*Osmerus eperlanus* (Linnaeus)
Smelt (Columbia River)	See eulachon
Smelt (Northwest Atlantic and Lake Michigan)	*Osmerus mordax* (Mitchill)
Smelt, pond	*Hypomesus olidus* (Pallas)
Smooth-hound	See dogfish, smooth
Snapper	*Lutjanus* spp.
Snoek (South Africa)	*Thyrsites atun* (Euphrasen)
Snook (Oceania)	*Australuzza novae-hollandiae* Günther
Soapy	See slimy
Sockeye (red) salmon	*Oncorhynchus nerka* (Walbaum)
Sole (East Pacific)	See rock sole
Sole (Europe)	*Solea vulgaris* (Day), syn. *Solea solea* (Linnaeus)
Sole (India)	*Cynoglossus semifasciatus*
Sole, lemon	See lemon sole
"Som" (Russia)	See sheatfish

English	Latin
Soupfin shark	*Galeorhinus zyopterus* (Jordan and Gilbert)
Spanish mackerel	*Scomberomorus maculatus* (Mitchill)
Sparling	See smelt
Spearfish	*Makaira* spp.
Speckled trout	See brook trout
Spotted catfish	See spotted wolf-fish
Spotted wolf-fish	*Anarhichas minor* Olafsen
Sprat (Europe)	*Clupea sprattus* (Linnaeus)
Sprat (New Zealand)	*Maugeclupea antipodum* (Hector)
Spurdog	See dogfish
Squirrel hake	*Urophycis chuss* (Walbaum)
Starry flounder (Pacific)	*Platichthys stellatus* Pallas, syn. *Paralichthys olivaceus* (Temminck and Schlegel)
Steelhead trout	See rainbow trout (North America)
Sterlet (Volga, Danube), "Sterljad" (Russian)	*Acipenser ruthenus* Linnaeus
Stingfish	See great weever
Stingray	*Dasyatis* spp.
Stockfish (South Africa)	*Merluccius capensis* Castlenau
Stone bass	*Polyprion americanus* (Bloch and Schneider)
Striped mullet	*Mugil cephalus* Linnaeus
Striped tuna	See skipjack
Sturgeon	*Acipenser sturio* Linnaeus
Sturgeon, Russian	*Acipenser güldenstädti* Brandt
Sturgeon (Danube), "beluga" (Russian)	*Huso huso* (Linnaeus)
Sturgeon (Caspian) "sevruga" (Russia)	*Acipenser stellatus* Pallas
Sturgeon, lake	*Acipenser fulvescens* Rafinesque
Sturgeon, shovelnose	*Scaphirhynchus platorhynchus* Rafinesque
Sturgeon, white	*Acipenser transmontanus* (Richardson)
Summer flounder	*Paralichthys dentatus* (Linnaeus)
Sunfish (West Atlantic)	*Lepomis* spp.
Sunfish, ocean (Europe)	*Mola mola* Linnaeus
Swordfish	*Xiphias gladius* Linnaeus
"Syrok" (Russia)	See "pelyad"
"Tarshiki" (Japan)	*Cheilodactylus macropterus*
Tench	*Tinca tinca* (Linnaeus)
Thickback	*Solea* (*Microchirus*) *variegata* (Donovan)
Thread herring	*Opisthonema oglinum* (LeSueur)
Thresher	*Alopias vulpinus* (Bonnaterre)
Tiger shark	*Galeocerdo cuvieri* (Peron and LeSueur)
Tomcod	*Microgadus tomcod* (Walbaum)
Torsk	See tusk
Tope (Atlantic)	*Galeorhinus galeus* (Linnaeus)

English	Latin
Tope (Oceania)	*Notogaleus rhinophanes* (Peron)
Torpedo	See electric ray
Trout, brook (North America)	*Salvelinus fontinalis* (Mitchill)
Trout (Australia)	*Galaxiids*
Trout, brown	*Salmo trutta* (*fario*) Linnaeus
Trout, cutthroat	*Salmo clarki* (Richardson)
Trout (Japanese) (marine)	See cherry salmon
Trout, lake (North America)	*Salvelinus* (*Cristivomer*) *namaycush* (Walbaum)
Trout, rainbow (North America)	*Salmo gairdneri irideus* Richardson
Trout, spotted sea (North America)	*Eriscion nebulosus* Cuvier and Valenciennes
Trout, sea (North America)	*Cynoscion regalis* (Bloch and Schneider)
Tuna (Red Sea)	*Gymosarda unicolor* (Rüppell)
Tunny	See bluefin tuna
Turbot (North Atlantic)	*Rhombus* (*Scopthalmus*) *maximus* (Linnaeus)
Turbot (Indo-Pacific, Australia)	*Psettodes erumei* (Schneider)
Turbot (North Pacific)	See arrow-toothed flounder
Tusk	*Brosme brosme* (Müller)
Twaite shad	*Clupea finta* (Cuvier)
Vendace	*Coregonus albula* (Linnaeus)
Vimba (Baltic, Mediterranean, Caspian)	*Vimba vimba* (Linnaeus)
"Vobla" (Russia)	See Caspian roach
"Wahoo"	See peto
Walleye (pike), blue	*Stizostedion vitreum glaucum* (Hubbs)
Walleye (pike)	*Stizostedion vitreum vitreum* (Mitchill)
Whiff	See megrim
Whitebait (Europe and North America)	*Clupea sprattus* or other small-sized *Clupea*
Whitefish, common	*Coregonus clupeaformis* (Mitchill)
Whitefluke	See flounder (Europe)
White amur	See grass carp
White bass	*Lepibema chrysops* Rafinesque
White-bellied skate	See skate, owl
White hake	*Urophycis tenuis* (Mitchill)
White perch (fresh-water)	See drum (fresh-water)
White perch (marine)	See sea perch
White sea bass (California)	*Cynoscion nobilis* Ayres
White shark	See man-eater
White sole (Europe)	See witch flounder
White steenbras	*Lithognathus lithognatus* (Cuvier)
White stumpnose (South Africa)	*Rhabdosargus globiceps* (Cuvier)

English	Latin
White sturgeon	*Acipenser transmontanus* (Richardson)
Whiting (Australia)	*Sillago* spp.
Whiting (Europe)	*Gadus* (*Odontogadus*) *merlangus* (Linnaeus)
Whiting (Northwest Atlantic)	*Merluccius bilinearis* (Mitchill)
Whiting, big-eye (Pacific)	See Alaska pollock
Winter carp	See bigmouth
Winter flounder	*Pseudopleuronectes americanus* (Walbaum)
Witch flounder	*Glyptocephalus cynoglossus* Linnaeus
Wolf-fish (Atlantic)	*Anarhicas lupus* Linnaeus
Wrasse (Europe)	Various species of Labridae
Wreckfish	See stone bass
Yellow bullhead	*Ictalurus natalis* (LeSueur)
Yellow pike	See walleye
Yellowfin (tuna)	*Thunnus albacora* (Lowe), syn. *Neothunnus macropterus*
Yellowfin sole	*Limanda aspera* (Pallas)
Yellowtail (Atlantic)	*Seriola lalandi* Valenciennes
Yellowtail (Australia)	*Trachurus declivis*
Yellowtail flounder (Northwest Atlantic)	*Limanda ferruginea* (Storer)

Latin	English
Abramis brama (Linnaeus)	Bream (fresh-water)
Acanthias vulgaris	See *Squalus acanthias*
Acanthocybium solandri (Cuvier and Valenciennes)	Peto, syn. "wahoo"
Acanthopagrus australis (Günther)	Black bream (Australia)
Acerina cernua (Linnaeus)	Pope, syn. ruffe
Acipenser fulvescens Rafinesque	Lake sturgeon
Acipenser güldenstädti Brandt	Russian sturgeon
Acipenser medirostris Ayres	Sakhalin sturgeon
Acipenser ruthenus Linnaeus	Sterlet (Volga, Danube) (Russian "sterljad")
Acipenser stellatus Pallas	"Sevruga" (Russian), syn. Caspian sturgeon
Acipenser sturio Linnaeus	Sturgeon, syn. Baltic sturgeon
Acipenser transmontanus (Richardson)	White sturgeon
Aldrichetta forsteri Cuvier and Valenciennes	Herring (Oceania)
Alepisaurus ferox Lowe	Lancetfish, syn. longnose
Alopias vulpinus (Bonnaterre)	Thresher

Latin	English
Alosa sapidissima Wilson	American shad
Ambloplites rupestris (Rafinesque)	Rock bass
Ammodytes spp.	Sand launce; see also *Gymnammodytes* spp.
Anarhichas lupus Linnaeus	Atlantic wolf-fish, syn. catfish
Anarhichas minor Olafsen	Spotted catfish, syn. spotted wolf-fish
Anchoviella indica van Hasselt, syn. *Engraulis (Stolephorus) indicus*	Anchovy (India)
Anguilla anguilla Linnaeus	Eel (European)
Anguilla aucklandii Philippi	Eel (Australia)
Anguilla japonica Temminck and Schlegel	Eel (Japanese)
Anguilla rostrata LeSueur	Eel (American)
Anoplopoma fimbria (Pallas)	Sablefish
Aorhamphus spp.	Garfish, sea (Australia)
Aplodinotus grunniens (Rafinesque)	Fresh-water drum
Arapaima gigas Cuvier	Pirarucu (South America)
Archosargus probatocephalus (Walbaum)	Sheepshead (marine)
Arctoscopus japonicus (Steindachner)	Sandfish
Argentina semifasciata Kishinouye	"Nigisu" (Japan)
Argentina sialis Gilbert	Argentine (Pacific)
Argentina silus Ascanius	Argentine (Atlantic)
Aristichthys nobilis (Richardson)	Bighead
Arnoglossus laterna (Walbaum)	Scaldfish
Arripis trutta Bloch and Schneider	Salmon (Australia), kahawai
Astroconger myriaster (Brevoort)	Conger eel (Northwest Pacific)
Atheresthes stomias (Jordan and Gilbert)	Arrow-toothed flounder (halibut)
Atractoscion aequidens Cuvier	Geelbek, syn. Cape salmon
Atractoscion nobilis (Ayres)	White sea bass (California)
Australuzza novae-hollandiae Günther	Snook (Oceania), syn. sea pike
Auxis thazard (Lacépède)	Frigate mackerel
Barbus barbus (Linnaeus)	Barbel
Belone belone Linnaeus	Gar pike, syn. garfish
Beryx splendens Lowe	Alfonsino
Boreogadus saida (Lepechin)	Polar (Arctic) cod, syn. "saika" (Russia)
Brama spp.	Sea bream (Northwest Atlantic); see also *Taractes princeps* (Johnson)
Brama raii (Bloch)	Pomfret (United States)
Branchiostegus japonicus (Houttuyn) and others	Blanquillo
Brevoortia patronus Goode	Gulf menhaden
Brevoortia tyrannus (Latrobe)	Menhaden (Atlantic)
Brosme brosme (Müller)	Cusk, syn. torsk, tusk

Latin	English
Calamus spp.	Porgies
Callorhynchus milii Bory de St. Vincent, syn. *Mormyrus petersi*	Elephant fish
Caranx bartholomaei (Cuvier)	Jack, see also *C. crysos* Mitchill
Caranx crysos (Mitchill)	Jack, see also *C. bartholomaei* (Cuvier)
Caranx hippos (Linnaeus)	Jack (Atlantic), syn. crevalle jack, and jack
Caranx sexfasciatus Quoy and Gaimard	Jack (Indian Ocean), syn. crevalle, kingfish
Caranx (*Trachurus*) *tracurus* (Linnaeus)	Horse mackerel, syn. saurel, maasbanker, scad, capefish, jack mackerel
Carassius auratus Linnaeus	Goldfish
Carassius carassius (Linnaeus)	Crucian carp, syn. German (or Prussian) carp
Carcharodon carcharias (Linnaeus)	Man-eater, syn. white shark
Caspiomyzon wagneri (Kessler)	Caspian lamprey
Cetorhinus maximus (Gunnerus)	Basking shark, syn. herring hog
Chanos spp.	Milkfish
Cheilodactylus macropterus	"Tarshiki" (Japan)
Chelidonichthys (*Trigla*) *kumu* Lesson and Garnot	Gurnard, red (Japan)
Chimaera monstrosa Linnaeus	Rabbitfish, syn. king of the herrings, silver shark
Chlorophthalmus albatrossis Jordan and Starks	Lizardfish
Chrysoblephus gibbiceps Cuvier	Red stumpnose (South Africa)
Chrysoblephus laticeps Cuvier	(Red) rowan (South Africa)
Chrysophris auratus (Bloch and Schneider)	Gilthead
Cirrhina orius mrigala Hamilton Buchanan	Morgan (India)
Cirrhina mittorella (Cuvier and Valenciennes)	Mud carp
Clarias batrachus Bleeker	"Magar" (India)
Clupanodon punctatus	Thread herring
Clupea (*Alosa*) *alosa* Linnaeus	Alewife (Europe), syn. Allis shad, shad, rock herring
Clupea finta (Cuvier)	Twaite shad
Clupea harengus Linnaeus	Herring (Atlantic), Maine sardine
Clupea harengus pallasi (Cuvier and Valenciennes)	Herring (Pacific)
Clupea harengus suworowi Rafinesque	Pechora herring
Clupea (*Sardina*) *pilchardus pilchardus* (Walbaum)	Pilchard sardine (Northwest Atlantic)
Clupea sprattus (Linnaeus)	Sprat (Europe), syn. sardine or brisling (Scandinavia), whitebait (Europe and North America)
Coilia dussumieri Cuvier and Valenciennes	"Mandeli" (India)

Latin	English
Colistium güntheri (Hutton)	Brill (Oceania)
Cololabis brevirostris (Peters)	Pacific saury; see also *C. saira* (Brevoort)
Cololabis saira (Brevoort)	Pacific saury; see also *C. brevirostris* (Peters)
Conger conger (Linnaeus)	Conger eel (Northeast Atlantic)
Conger oceanicus (Mitchill)	Conger eel (Northwest Atlantic)
Coregonus albula (Linnaeus)	Vendace
Coregonus (*Leucichthys*) *artedii* (LeSueur)	Cisco
Coregonus autumnalis (Pallas)	Arctic cisco, syn. "Omul" (Russian)
Coregonus clupeaformis (Mitchill)	Whitebait (Australia), syn. lake herring (Lake Michigan), or common whitefish
Coregonus lavaretus (Linnaeus)	Powan, syn. "sig" (Russia), "sik" (Scandinavian)
Coregonus muksun (Pallas)	"Muksun" (Russia)
Coregonus nasus (Pallas)	Broad whitefish
Coregonus oxyrhynchus Linnaeus	Houting (Scandinavian lakes, Baltic, North Sea)
Coregonus peled (Gmelin)	"Pelyad" (Russia) or "syrok" (Russia)
Coregonus sardinella Valenciennes	Siberian cisco, syn. least cisco
Coryphaena hippurus Linnaeus	Dolphin, syn. dorado
Cristivomer namaycush, syn. *Salvelinus namaycush* (Walbaum)	Char (Great Lakes), lake trout
Ctenopharyngodon idella (Cuvier and Valenciennes)	Grass carp, syn. white amur (Russia)
Cyclopterus lumpus Linnaeus	Lumpsucker, syn. lumpfish
Cynoglossus semifasciatus Day	Sole (India)
Cynoscion regalis (Bloch and Schneider)	Weakfish, syn. sea trout (North America)
Cynoscion nobilis (Ayres)	White sea bass (California)
Cyprinus carpio (Linnaeus)	Common carp
Cypselurus spp.	Flying fishes
Dasyatis spp.	Stingray
Decapterus punctatus (Agassiz)	Round scad, syn. cigarfish
Decapterus muroadsi (Temminck and Schlegel)	"Muroaji" (Japan)
Dentex (*Petrus*) *rupestris* (Valenciennes)	Red steenbras
Diaphus coeruleus Klunzinger	Lantern fish
Dorosoma cepedianum (LeSueur)	Gizzard shad

Latin	English
Eleginus gracilis (Tilesius)	Saffron cod, syn. Far East "navaga"
Eleginus navaga (Pallas)	"Navaga" (Russia)
Elops saurus Linnaeus	Cape salmon, syn. ladyfish
Emissola antarctica (Günther)	Smoothhound (dogfish), syn. "manga"
Enedrias nebulosus (Temminck and Schlegel)	Blenny
Engraulis (*Stolephorus*) *indicus*	See *Anchoviella indica*
Engraulis japonicus (Houttuyn)	Anchovy (Japan)
Engraulis mordax (Girard)	Anchovy, northern (East Pacific)
Engraulis pseudoharengus Wilson, syn. *E. encrasicholus* Linnaeus	Anchovy (Europe)
Entosphenus japonicus Martens	See *Lampetra japonica*
Eopsetta jordani (Lockington)	Petrale sole
Epinephelus spp.	Grouper (Atlantic)
Erilepis zonifir Linnaeus	Black cod
Eriscion nebulosus Cuvier and Valenciennes	Spotted sea trout
Esox lucius (Linnaeus)	Northern pike
Esox masquinongy Mitchill	Muskellunge
Esox niger LeSueur	Chain pickerel
Etrumeus micropus (Schlegel)	Round herring, syn. herring (Indo-Pacific)
Etrumeus sadina (Mitchill)	Herring (Caribbean), syn. Atlantic round herring
Eumakaira negra (Nakamura), syn. *Makaira nigricans marlina* (Lacépède)	Black marlin
Euthynnus affinis (Cantor)	Little tuna (Pacific and Indian Oceans)
Euthynnus alletteratus (Rafinesque)	Little tuna (Atlantic, Mediterranean)
Euthynnus (*Katsuwonus*) *pelamis* (Linnaeus)	Skipjack, syn. oceanic bonito
Gadus callarias (Linnaeus), syn. *Gadus morhua* Linnaeus	Cod (Atlantic), codling
Gadus luscus Linnaeus	Bib, syn. pout, pouting
Gadus (*morhua*) *macrocephalus* (Tilesius)	Pacific cod, syn. gray cod
Gadus (*Odontogadus*) *merlangus* (Linnaeus)	Whiting (Europe)
Gadus minutus Linnaeus	Poor cod
Gadus ogac Richardson	Greenland cod
Gadus (*Micromesistius*) *poutassou* (Risso)	Poutassou, syn. blue whiting
Galaxias spp.	Trout (Australia)
Galeocerdo cuvieri (Peron and LeSueur)	Tiger shark
Galeorhinus australis	Shark (Oceania)
Galeorhinus galeus (Linnaeus)	Tope (Atlantic)

Latin	English
Galeorhinus zyopterus (Jordan and Gilbert)	Soupfin shark
Galeus vulgaris (Fleming)	Tope (Atlantic)
Genypterus blacodes Bloch and Schneider	Ling (Oceania)
Genypterus capensis Smith	Kingklip, syn. koningklip
Genypterus microstommus Regan	Ling (Oceania)
Girardinus guppyi Günther	Guppy
Girella tricuspidata	Blackfish (Australia)
Girella nigricans (Ayres)	Opaleye
Girella punctata Gray	Greenfish
Glossanodon (*Argentina*) *semifasciatus* (Kishinouye)	"Nigisu" (Japan)
Glossogobius (*Gobius*) *giuris* Hamilton Buchanan	"Bele" or "gula" (India)
Glyptocephalus cynoglossus Linnaeus	Witch flounder (United States), syn. white sole (Europe), pole dab (Europe)
Glyptocephalus stelleri (Schmidt)	Japanese sole
Gymnammodytes spp.	Sand launce; see also *Ammodytes spp.*
Gymnosarda nuda	Dogtooth tuna (Red Sea)
Harengula pensacolae Goode and Bean	Scaled sardine, syn. razorbelly
Harpodon nehereus Günther	Bombay duck, syn. "bombil" (India)
Helioperca incisor Cuvier and Valenciennes	See *Lepomis macrochirus* Rafinesque
Hemirhamphus spp.	Garfish, sea (Australia)
Hemitripterus americanus (Gmelin)	Sea raven
Hexea (*Rexea*) *solandri* (Cuvier)	Hake (Australia)
Hilsa ilisha Regan	See *Macrurus ilisha* (Buchanan Hamilton)
Hippoglossoides classodon Jordan and Gilbert	Flathead sole
Hippoglossoides platessoides (Fabricius)	American plaice
Hippoglossus stenolepis (Schmidt)	Halibut (Pacific)
Hippoglossus hippoglossus, syn. *H. vulgaris* Linnaeus	Halibut (Atlantic)
Hirundichthys affinis (Günther)	Flying fish
Holocanthus spp.	Angelfish (United States); see also *Pomocanthus* spp.
Hucho hucho (Linnaeus)	Huchen, syn. Danube salmon
Hucho taimen (Pallas)	Amur salmon, also in Upper Volga and the Pechora River.
Huso huso (Linnaeus)	"Beluga," syn. great white sturgeon, sturgeon (Danube)
Hypomesus olidus (Pallas)	Pond smelt
Hyporhamphus spp.	Garfish, sea (Australia)
Hypothalmichthys molitrix Valenciennes	Silver carp

Latin	English
Ictalurus spp.	Bullhead or catfish (fresh-water)
Ictalurus natalis (LeSueur)	Yellow bullhead
Ictiobus bubalus Rafinesque	Smallmouth buffalo
Ictiobus cyprinellus (Valenciennes) or other *I.* species	Buffalofish, syn. bigmouth or winter carp
Istiophorus spp.	Sailfish
Isopsetta isolepis (Lockington)	Butter sole
Johnius hololepidotus Lacépède	Kabeljou (South Africa)
Johnius (*Sciaena*) *sina* (Cuvier)	Jewfish (India), syn. "ghol"
Katsuwonus pelamis (Linnaeus)	See *Euthynnus pelamis* (Linnaeus)
Labeo rohita Buchanan Hamilton	"Rohu" (India)
Labrax lupus	See *Morone labrax Linnaeus*
Labridae, various species	Wrasse (Europe)
Lagodon rhomboides (Linnaeus)	Sailors-choice
Lamna nasus (Bonnaterre)	Porbeagle, syn. mackerel shark, salmon shark
Lampetra ayresii (Günther)	River lamprey
Lampetra fluviatilis (Linnaeus)	River lamprey, see also *L. ayresii*
Lampetra japonica (Martens)	Japanese lamprey
Lampris regius (Bonnaterre)	Opah
Lateolabrax japonicus (Cuvier)	Sea perch (Japan), syn. sea bass
Lates calcarifer Günther	Giant perch (Australia), syn. barragmundi
Leiognathus (*Equula*) *bindus* (Cuvier and Valenciennes)	Silverbelly (India)
Leiognathus equula Forskål	Slimy, syn. soapy
Lepibema chrysops Rafinesque	White bass
Lepidopsetta bilineata (Ayres)	Rock sole
Lepidopus caudatus (Euphrasen)	Scabbardfish (Northeast Atlantic)
Lepidorhombus whiff-iagonis (Walbaum)	Megrim, syn. whiff, sailfluke
Lepidotrigla microptera Günther	Gurnard (Japan), sea robin; see also *Chelidonichthys kumu*
Lepomis spp.	Sunfish (West Atlantic), syn. "peperek" (Indonesia)
Lepomis macrochirus Rafinesque	Bluegill
Leptoscarus spp.	Parrot fish

Latin	English
Leuciscus idus Linnaeus	Ide, syn. "yaz" (Russia)
Leuciscus (*Rutilus*) *rutilus* (Linnaeus)	Roach (Europe)
Leucichthys spp.	Chub (North America)
Limanda aspera (Pallas)	Yellowfin sole
Limanda ferruginea (Storer)	Yellowtail flounder (Northwest Atlantic)
Limanda limanda (Linnaeus)	Dab (Europe)
Limanda yokohamae, syn. *Paralichthys olivaceus* (Temminck and Schlegel)	Flatfish (Japan), syn. "hirame"
Liopsetta exilis (Jordan and Gilbert)	Slender sole (Northeast Pacific)
Liopsetta glacialis (Pallas)	Polar plaice, syn. Arctic flounder
Liopsetta putnami (Gill)	Small mouth flounder (Canada)
Lithognathus lithognathus Cuvier	White Steenbras, syn. whitefish (South Africa)
Lophius americanus Valenciennes	Angler (Northwest Atlantic), syn. goosefish
Lophius litulon Jordan	Angler (Japanese)
Lophius piscatorius Linnaeus	Anglerfish, syn. monkfish, fishing frog, or silver salmon
Lophopsetta maculata (Mitchill)	Brill (Northwest Atlantic)
Lota lota (lacustris) (Walbaum), syn. *Lota vulgaris*	Burbot, syn. "nalim" (Russia)
Lota maculosa (LeSueur)	Ling (Canada) (fresh-water)
Lucioperca lucioperca (Linnaeus)	Pike-perch (Europe)
Lutjanus blackfordi Goode and Bean	Red snapper
Macrourus spp.	Rattail, syn. grenadier
Macrozoarces americanus (Bloch and Schneider)	Ocean pout, syn. eelpout
Macrura ilisha (Buchanan Hamilton), syn. *Hilsa ilisha* Reagan	Indian shad, syn. "pala" (India)
Makaira albida (Poey)	White marlin
Makaira ampla (Poey)	Black marlin
Makaira audax (Philippi)	Striped marlin
Makaira nigricans Lacépède	Blue marlin
Mallotus catervarius (Pennant)	Capelin (Arctic)
Mallotus socialis (Pallas)	Capelin (Pacific)
Mallotus villosus (Müller)	Capelin (Atlantic)
Marlina marlina Linnaeus	White marlin, syn. *Makaira albida* (Poey)
Maugeclupea antipodum (Hector)	Sprat (New Zealand)
Megastomatobus cyprinella (Cuvier and Valenciennes)	Bigmouth, syn. buffalofish, winter carp
Melanogrammus (*Gadus*) *aeglefinus* Linnaeus	Haddock (Atlantic)
Merluccius bilinearis (Mitchill)	Whiting (Northwest Atlantic)

Latin	English
Merluccius capensis Castlenau	Stockfish (South Africa), syn. hake (South Africa)
Merluccius gayi Guich	English hake (Oceania)
Merluccius merluccius Linnaeus	Hake (Atlantic)
Merluccius productus Ayres	Hake (Pacific)
Microchirus variegata (Donovan)	See *Solea variegata* (Donovan)
Microgadus tomcod (Walbaum)	Tomcod
Micropogon undulatus (Linnaeus)	Croaker (Atlantic)
Micropterus dolomieu Lacépède	Smallmouth bass
Microstomus (*Pleuronectes*) *microcephalus* (Donovan)	Lemon sole (Northeast Atlantic)
Microstomus pacificus (Lockington)	Dover slime sole, syn. Dover sole (Northeast Pacific)
Microstomus stelleri	See *Glyptocephalus stelleri* (Schmidt)
Mola mola Linnaeus	Ocean sunfish (Europe)
Molva dipterygia (Pennant)	Blue ling
Molva elongata Risso	Ling (Mediterranean)
Molva molva (Linnaeus)	Common ling
Molva spp.	Ling
Monacanthus cirrhifer Temminck and Schlegel	Leatherfish, file-fish
Mormyrus oxyrhynchus	Elephantfish (Nile)
Morone americanus (Gmelin)	White perch, syn. sea perch
Morone labrax (Linnaeus), syn. *Labrax lupus*	Bass, syn. salmon bass
Mugil speigleri Bleeker	Mullet (India), syn. "boya"
Mugil cephalus Linnaeus	Striped mullet
Mugil spp.	Mullet (in general)
Mullus auratus Jordan and Gilbert	Red mullet (West Atlantic)
Mullus surmulletus Linnaeus	Red mullet (Europe)
Mustelus canis (Mitchill)	Smooth dogfish (Northwest Atlantic)
Mustelus mustelus Linnaeus	Smooth dogfish, (Northeast Atlantic)
Mylocheilus caurinus (Richardson)	Peamouth
Mylopharyngodon piceus (Richardson)	Blackamur
Myoxocephalus octodecemspinosus (Mitchill)	Longhorn sculpin
Neothunnus macropterus Temminck and Schlegel	Yellowfin (tuna)
Niphon spinosus Cuvier	Common bass (Japan)
Notogaleus rhinophanes (Peron)	Tope (Oceania)
Odonthestes (*Basilichthys*) *bonariensis* (Cuvier and Valenciennes)	Pejerrey (Argentina); (in Brazil: peixe-rei)

Latin	English
Odontogadus merlangus (Nordm.)	See *Gadus merlangus* (Linnaeus)
Oncorhynchus gorbuscha (Walbaum)	Pink salmon, syn. humpback salmon
Oncorhynchus keta (Walbaum)	Chum salmon, syn. dog salmon
Oncorhynchus kisutch (Walbaum)	Silver salmon, syn. jack salmon, coho salmon, or silversides
Oncorhynchus masou (Brevoort)	Cherry salmon, syn. Japanese salmon (trout)
Oncorhynchus nerka (Walbaum)	Sockeye (red) salmon
Onchorhynchus tschawytscha (Walbaum)	King salmon, syn. Chinook salmon, black salmon, or chub salmon (spring type)
Ophiocephalus spp.	Blackfish, syn. "maral" (India)
Ophiodon elongatus (Girard)	Ling cod, syn. greenling
Opisthonema oglinum (LeSueur)	Thread herring
Orcynopsis unicolor (St. Hilaire)	Plain bonito
Oryzias latipes (Temminck and Schlegel)	"Killifish" (Japan)
Osmerus eperlanus (Linnaeus)	Smelt, syn. sparling
Osmerus mordax (Mitchill)	Smelt (Northwest Atlantic and Lake Michigan)
Pachymetopon blochii (Valenciennes)	Hottentot
Pagellus centrodontus (de la Roche)	Common sea bream, syn. red bream (Northeast Atlantic)
Pagellus erythrinus (Linnaeus)	Pagel, pagello (Portugal and Italy)
Pagellus lithognathus	See *Lithognathus lithognathus* (Cuvier)
Pagrosomus spp.	Porgy, syn. sea bream
Paralichthys dentatus (Linnaeus)	Summer flounder
Paralichthys olivaceus (Temminck and Schlegel)	"Hirami" (Japan), syn. to *Platichthys stellatus* (Pallas)
Parathunnus sibi (Temminck and Schlegel)	syn. *Thynnus obesus* Lowe
Parophrys vetulus (Girard)	English sole (Northeast Pacific)
Peltotretis flavilatus Waite	Lemon sole (Oceania)
Peltorhamphus novae-zeelandiae Günther	English sole (Oceania), syn. New Zealand common sole
Perca flavescens (Mitchill)	Perch (North America), syn. yellow perch
Perca fluviatilis Linnaeus	Perch (Europe, Asia), syn. lake or river perch
Peristedion spp.	Sea robin; see also *Prionotus* spp.
Petromyzon fluviatilis Linnaeus	See *Lampetra fluviatilis*

Latin	English
Petromyzon marinus Linnaeus	Sea lamprey (Atlantic and Great Lakes)
Petrus rupestris (Valenciennes)	Red steenbras
Phoxinus phoxinus (Linnaeus)	Minnow
Phycis (Urophycis) blennoides Brünnich	Greater forkbeard, syn. forked hake
Physiculus (Pseudophycius) bachus (Bloch and Schneider)	Red Cod (Oceania), syn. "hoka"
Pilodictis olivaris Rafinesque	Catfish (fresh-water)
Platichtys stellatus (Pallas), syn. *Paralichthys olivaceus* (Temminck and Schlegel)	Starry flounder (Pacific), syn. "hirame" (Japan)
Platycephalus indicus Linnaeus	Flathead (Pacific)
Platypoecilus maculatus	Mexican platyfish
Plecoglossus altivelis Temminck and Schlegel	"Ayu" (Japan)
Pleurogrammus azonus Jordan and Metz, syn. *P. monopterygius* (Pallas)	Atka mackerel
Pleuronectes cynoglossus (Linnaeus)	See *Glyptocephalus cynoglossus* (Linnaeus)
Pleuronectes (Limanda) ferruginea (Linnaeus)	Dab (Atlantic), longhead, yellowtail flounder
Pleuronectes flesus Linnaeus	Flounder (Europe), syn. whiteflake, fluke, butt
Pleuronectes microcephalus	Lemon sole (Atlantic)
Pleuronectes platessa Linnaeus	Plaice (Northeast Atlantic)
Pneumatophorus (Scomber) colias (Gmelin)	Chub mackerel
Pneumatophorus (Scomber) diego (Ayres)	Pacific mackerel
Pneumatophorus (Scomber) japonicus (Houttuyn)	Japanese mackerel
Pollachius pollachius (Linnaeus)	Pollock (Europe), syn. pollack
Pollachius virens (Linnaeus)	Coalfish, syn. saithe, coley, sea salmon
Polydactylus indicus Shaw	Indian salmon, syn. "dara" or "kuru"
Polynemus indicus (Shaw)	See *Polydactylus indicus*
Polyprion americanus (Bloch and Schneider)	Stone bass, syn. wreckfish
Polyprion oxygeneios (Bloch and Schneider)	Grouper (Oceania), syn. "hapuka" (Australia)
Pomacanthus spp.	Angelfish (United States); see also *Holacanthus* spp.
Pomatomus saltatrix (Linnaeus)	Bluefish, (United States), syn. elf (South Africa), anchova (Portugal)
Pomolobus aestivalis (Mitchill)	Alewife (United States, Canada)
Pomolobus pseudoharengus (Wilson)	Alewife (United States, Canada)
Pomoxis spp.	Crappie

Latin	English
Poronotus triacanthus (Peck)	Butterfish
Prionace glauca (Linnaeus)	Great blue shark
Prionotus spp.	Sea robin; see also *Peristedion* spp.
Psettichthys melanostictus Girard	Sand sole (flounder) (Pacific)
Psettodes erumei (Schneider)	Turbot (Indo-Pacific, Australia) "Kalankan" (Indonesia)
Pseudolabrus gracilis (Steindachner)	Wrasse (Japan)
Pseudolabrus japonicus (Houttuyn)	See *Pseudolabrus gracilis* (Steindachner)
Pseudopleuronectes americanus (Walbaum)	Lemon sole (Northwest Atlantic), syn. winter flounder (Northwest Atlantic)
Pygosteus pungitius (Linnaeus)	Arctic stickleback
Raja batis Linnaeus	Skate, syn. blue, bluet, grey skate
Raja brachyura Lafont	Blonde ray
Raja circularis Couch	Sandy ray
Raja clavata Linnaeus	Thornback ray
Raja erinacea Mitchill	Little skate
Raja fullonica Linnaeus	Shagreen ray
Raja lintea Fries	Sharp-nosed skate
Raja marginata Lacépède	Owl skate, syn. white-bellied skate, bordered skate, Burton skate
Raja microcellata Montagu	Painted ray
Raja montagui Fowler	Spotted, Homelyn ray
Raja naevus Müller and Henle	Cuckoo ray
Raja oxyrhynchus Linnaeus	Long-nosed skate
Raja radiata Donovan	Starry ray
Raja undulata Lacépède	Undulate, marbled ray
Rastrelliger kanagurta (Cuvier)	Indian Mackerel
Reinhardtius hippoglossoides (Walbaum)	Greenland halibut, syn. mock halibut, bastard halibut
Rhabdosargus globiceps (Cuvier)	White stumpnose (South Africa)
Rhina (*Squatina*) *squatina* Linnaeus	Monkfish, syn. angelfish (Europe), sharkray, fiddlefish
Rhombosolea spp.	Flounder (Oceania)
Rhombosolea plebeia (Richardson)	Dab (Oceania)
Rhombus laevis (Rondelet)	Brill (North Sea)
Rhombus (*Scopthalmus*) *maximus* (Linnaeus)	Turbot (North Atlantic)
Roccus saxatilis (Walbaum)	Striped bass
Rutilus rutilus caspicus (Jak.)	Caspian roach, syn. "vobla" (Russian)

Latin	English
Salmo clarki (Richardson)	Cutthroat trout
Salmo gairdneri irideus Richardson	Rainbow trout (North America), syn. steelhead trout
Salmo mykiss Walbaum	Kamchatka river salmon
Salmo penshinensis Pallas	Kamchatka salmon
Salmo salar Linnaeus	Salmon (Atlantic), syn. parr; see also huchen
Salmo sebago Girard	Sebago salmon
Salmo trutta (*fario*) Linnaeus	Brown trout
Salmo trutta trutta Linnaeus	Sea trout
Salvelinus spp.	Char
Salvelinus alpinus Linnaeus	Arctic char
Salvelinus fontinalis (Mitchill)	Brook trout (North America), syn. speckled trout
Salvelinus malma (Walbaum)	Dolly Varden
Salvelinus (*Christivomer*) *namaycush* (Walbaum)	Lake trout (North America), syn. Great Lakes char
Sarda australis	Bonito (Australia)
Sarda chilensis Cuvier and Valenciennes	Bonito (Chile)
Sarda lineolata (Girard)	Bonito (California)
Sarda orientalis (Temminck and Schlegel)	Stripped bonito
Sarda sarda Bloch	Bonito (Atlantic)
Sardina caerulea (Girard)	Pilchard (Pacific); see *Sardinops* (*Sardina*) *caerulea* Girard
Sardina (*Sardinops*) *melanosticta* (Temminck and Schlegel), syn. *Sardinops sagax melanosticta* (Schlegel)	Sardine (Northwest Pacific)
Sardina (*Sardinops*) *neopilchardus* (Steindachner)	Sardine (Australia)
Sardina pilchardus sardina Walbaum	Pilchard (Mediterranean)
Sardinella aurita Cuvier and Valenciennes	Sardine or pilchard (West Africa)
Sardinella fimbriata (Valenciennes)	Sardine (India)
Sardinella longiceps Valenciennes	Oil sardine (India)
Sardinella neopilchardus (Steinacher)	Pilchard or sardine (Oceania)
Sardinops (*Sardina*) *caerulea* Girard	Pilchard or sardine (Northeast Pacific)
Sardinops (*Sardina*) *ocellata* (Jenyns)	Pilchard or sardine (South Africa) syn. *Sardina sagax*
Sardinops sagax sagax (Jenyns)	Sardine (Southwest Pacific)
Scaphirhynchus platorynchus Rafinesque	Shovelnose sturgeon
Scardinius erythrophthalmus (Linnaeus)	Rudd, syn., red-eye
Sciaena aquila Linnaeus	Meagre, syn. maigre or shadefish

Latin	English
Sciaena diacanthus Günther	"Ghol" (India)
Scomber grex (Mitchill)	Mackerel (Caribbean)
Scomber japonicus Houttuyn, syn. *S. colias*	Pacific mackerel, syn. chub mackerel, blue mackerel
Scomber maculatus (Mitchill)	See *Scomberomorus maculatus*
Scomber scombrus Linnaeus	Mackerel (Atlantic)
Scomberomorus maculatus (Mitchill)	Spanish mackerel
Scomberomorus regalis (Bloch)	King mackerel, syn. great kingfish, pintado sierra; see also *Sierra cavalla* Cuvier
Scomberesox saurus (Walbaum)	Saury pike, syn. skipper
Scophthalmus maximus Linnaeus	See *Rhombus laevis* (Linnaeus)
Scylliorhinus capensis (Müller and Henle)	Dogfish (South Africa)
Scylliorhinus stellaris Linnaeus	Greater (large) spotted dogfish
Sebastes marinus (*marinus*) (Linnaeus)	Ocean perch, syn. Northeast Atlantic redfish, Norway haddock
Sebastes mentella (*marinus*) (Travin)	Redfish (Northwest Atlantic), syn. ocean perch
Sebastichthys capensis (Gmelin)	Jacopever (South Atlantic)
Sebastiscus marmoratus (Cuvier)	Rockfish (Japan)
Sebastodes inermis (Cuvier and Valenciennes)	Brown rockfish (China)
Sebastodes flammeus (Jordan and Starks)	Rockfish (Northwest Pacific)
Sebastomus rosaceus Girard	Rosy rockfish (Northeast Pacific), syn. corsair
Sebastosomus mystinus (Jordan and Gilbert)	Blue rockfish (Northeast Pacific)
Seriola lalandi Valenciennes	Yellowtail (Atlantic)
Seriola quinqueradiata (Temminck and Schlegel)	Yellowtail (Northeast Pacific)
Serrasalmus (*Rooseveltiella*) *nattereri* (Kner)	Piranha
Sierra cavalla Cuvier	King mackerel, syn, sierra; see also *Scomberomorus regalis* (Bloch)
Sillago spp.	Smelt (South Africa), syn. pescadinha (Portugal), whiting (Australia)
Siluris glanis (Linnaeus)	Sheatfish, syn. "som" (Russia)
Solea lascaris (Risso)	Sand sole (Europe)
Solea solea (Linnaeus)	Sole (Europe); see also *Solea vulgaris* (Day)
Solea (*Microchirus*) *variegata* (Donovan)	Thickback
Solea vulgaris (Day)	Syn. to *Solea solea* (Linneaus)
Somniosus microcephalus (Bloch and Schneider)	Greenland shark
Sphaeroides spp.	Puffers
Sphyraena spp.	Barracuda, syn. sea pike
Sphyraena picuda Bloch and Schneider	Barracuda (Japan)

Latin	English
Sphyrna zygaena Linnaeus	Hammerhead (shark)
Squalus acanthias (Linnaeus) syn. *Sq. suckleyi* (Girard)	Dogfish, syn. fluke, piked dogfish, rock salmon, sourdog
Squalus mitsukurii Jordan and Fowler	Dogfish (Japan)
Squatina squatina (Linnaeus)	Angelfish, syn. monkfish, fiddlefish
Stenodus leucichthys (Güldenstadt)	Inconnu
Stenodus leucichthys nelma (Pallas)	"Nelma" (Russian)
Stenotomus spp.	Porgies
Stenotomus versicolor (Mitchill)	Scup
Stereolepis gigas Ayres	Giant sea-bass, syn. black sea bass
Stizostedion canadense (Smith)	Sauger
Stizostedion vitreum glaucum (Hubbs)	Blue walleye (pike)
Stizostedion vitreum vitreum (Mitchill)	Walleye (pike)
Stromateus cinereus Bloch	White or silver pomfret (India), syn. "halwa"
Stromateus niger Bloch	Black pomfret (India), syn. "garangu"
Synaptura marginata Boulenger	Sole (South Africa), syn. tong; see also *Austroglossis microlepis* and *A. pectoralis*
Taractes princeps (Johnson)	Sea bream (Northwest Atlantic); see also *Brama* spp.
Tetrapturus spp.	Spearfish
Thaleichthys pacificus (Richardson)	Eulachon; Columbia River smelt
Theragra chalcogramma (Pallas)	Alaska pollock, syn. walleye pollock, "mintaí" (Russian), whiting, big-eye (Pacific) or Korean cod
Thunnus alalunga Bonnaterre	Albacore
Thunnus albacora (Lowe)	Yellowfin tuna
Thunnus atlanticus (Lesson)	Blackfin tuna
Thunnus thynnus (Linnaeus)	Bluefin tuna
Thunnus thynnus orientalis (Temminck and Schlegel)	Japanese tuna
Thymallus arcticus (Pallas)	Arctic grayling
Thymallus grubei	Grayling (China)
Thymallus thymallus (Linnaeus)	Grayling (fresh-water) (North America and Europe)
Thyrsites atun (Euphrasen)	Barracouta (Australia), snoek (South Africa)
Tiaroga cobitis Girard	Loach (minnow)
Tinca tinca (Linnaeus)	Tench
Torpedo spp.	Electric ray

Latin	English
Trachinotus blochii (Lacépède)	Pampano (Indo-Pacific)
Trachinotus carolinus (Linnaeus)	Common pampano
Trachinus draco Linnaeus	Great weever
Trachinus vipera Cuvier and Valenciennes	Angler, syn. lesser weever, stingfish
Trachurus declivis (Jenyns)	Yellowtail (Australia), syn. mackerel (Oceania)
Trachurus japonicus (Temminck and Schlegel)	Horse mackerel (Japanese)
Trachurus novae-zelandiae Richardson	Scad (Australia), syn. horse mackerel (Oceania)
Trachurus symmetricus (Ayres)	Horse mackerel (California)
Trachurus trachurus Linnaeus	Horse mackerel, capefish
Tribolodon hakonensis hakonensis (Günther)	Dace (Northwest Pacific)
Trichiurus lepturus Linnaeus	Scabbard-fish (Northwest Atlantic), hairtail (Japan)
Trigla capensis Cuvier	Gurnard (red) (South Africa), syn. "knoorhaan"
Trigla hirundo Linnaeus	Yellow gurnard
Urophycis chuss (Walbaum)	Squirrel hake
Urophycis tenuis (Mitchill)	White hake
Vimba vimba (Linnaeus)	Vimba (Baltic, Mediterranean, Caspian)
Vomer declivifrons Meek and Hildebrand	Moonfish (Pacific)
Vomer setapinnis (Mitchill)	Moonfish (Atlantic)
Wallago attu Bleeker	"Shirada" (India)
Xiphias gladius Linnaeus	Swordfish
Zeus australis Richardson	John Dory (Australia)
Zeus faber Linnaeus, syn. *Zeus capensis* Cuvier	John Dory (United Kingdom and South Africa)
Zeus japonicus Valenciennes	John Dory (Japan)

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